Journal
of the
British Interplanetary Society

VOL. 11, No. 3 XLVI May, 1952

THE DESIGN OF ROCKET MOTORS

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A paper read to the Midlands Branch of the British Interplanetary Society in Birmingham on 12th January, 1952.

ABSTRACT

The process of designing a liquid-fuel rocket motor is described. It is first necessary to decide on the duration, thrust, and combustion chamber pressure of the motor, and on the propellants. On these points depend the choice between pump feed and pressurized tank feed, materials, and to some extent the design of pumps, turbine, and combustion chamber.

The main components are considered in turn, but it is shown that pumps and turbine should be designed together. Impulse turbines and high-speed centrifugal pumps are almost invariably used, and the importance of avoiding cavitation is stressed. A method is outlined by which the shape and size of the combustion chamber may be determined, also the chamber wall thickness, which is shown to be a compromise between heat transfer and mechanical strength. Injectors, igniters and valves are briefly discussed and it is considered to be essential that control systems, particularly of aircraft motors, should embody adequate safety devices even if this involves a weight penalty.

In giving this paper I have assumed previous knowledge of how a rocket motor works and what its main components are.

Before any real design work can be started, we must find the answers to four questions, which are best answered in the following order:—

(1) For how long is the rocket motor to run?
(2) What is to be its thrust?
(3) What propellants is it to burn?
(4) What is to be its combustion chamber pressure?

The answer to the first three questions will usually be supplied to the designer. Questions 1 and 2 should be considered together, since the product of thrust and duration, known as "total impulse," decides whether the unit is to have pressurized tanks or propellant pumps. As the total impulse increases, so the weight of pressurizing gas increases, and as this is usually nitrogen stored in high-pressure bottles there comes a point where the weight of pressurant and tanks is greater than the weight of the necessary propellant pumps and the means for driving them. Fig. 1 shows that pressurized tank feed becomes impracticable for total impulses much over 200,000 lb.-sec.

Apart from its connection with total impulse, thrust is actually the least important factor to be considered, since changes of thrust can often be met by changes of detail design such as width of pump passages, diameter of combustion chamber throat, and so on. Provided that the total impulse does not then exceed the critical value, thrust changes of up to 50 per cent. can often be allowed at a late stage of the design.

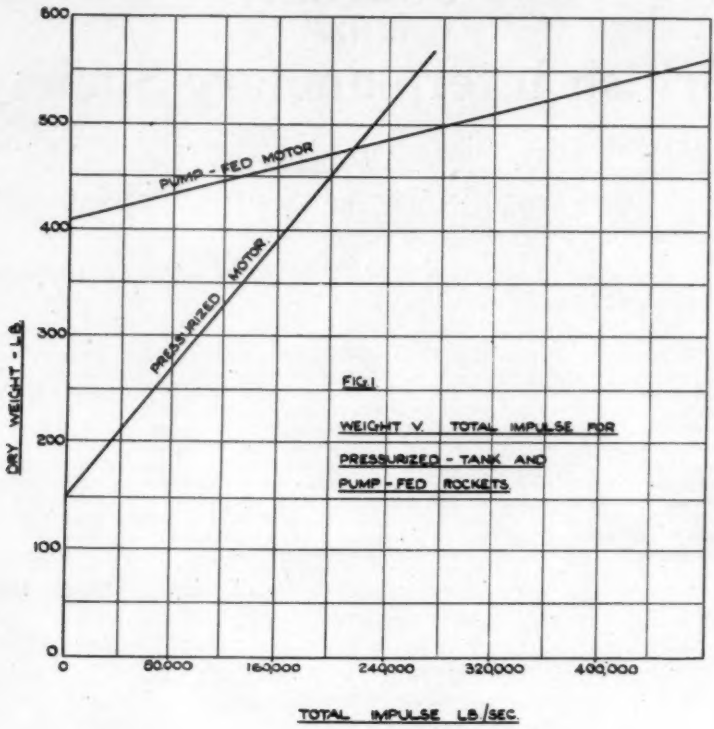

FIG. 1.

The choice of propellants is important because the oxidizer in particular affects the design of several components. The construction of propellant pumps and the means of cooling the combustion chamber are two of the more important points concerned. Opinions differ over the choice of oxidizer; my personal choice for an aircraft rocket motor would be liquid oxygen, since the main risk in handling it is that of frostbite, and slight leakage from joints would not corrode the aircraft structure. For a missile, nitric acid would be preferable, since it can be stored more or less indefinitely in sealed tanks. The choice of fuel is usually dictated by convenience.

The fourth question, combustion chamber pressure, should be answered at an early stage of the project, because, again, the design of several components depends on the answer. If pressurized tanks are used, their strength and consequently their weight must be increased as the chamber pressure is raised. If it is to be a pump-fed unit, the diameter and speed of the pumps will be influenced by the chamber pressure, and the speed in turn will affect the design of the turbine if one is used. Finally, the weight of the combustion chamber

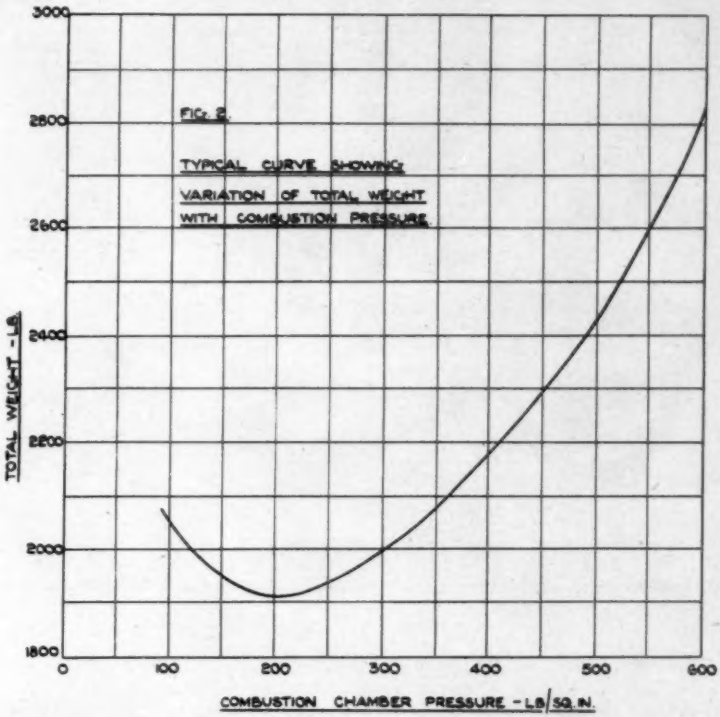

FIG. 2.

itself will go up as its working pressure is increased. Now although a higher combustion pressure gives a greater specific impulse and reduced propellant consumption, we eventually reach a point where the weight of propellants saved is offset by the increased weight of the motor. Somewhere there is an optimum pressure, and a curve similar to Fig. 2 should be drawn at as early stage as possible in the design of a particular motor.

When we have settled these preliminary points we can consider the design in more detail. The work to be done depends on the type of motor and the propellants it will burn. I propose to discuss the particular case of a pump-fed aircraft rocket motor, and where this differs from other kinds to point out where the difference lies.

It is always doubtful whether the design of tanks lies within the scope of the rocket engineer, but in some cases the nature of the propellants calls for special treatment so it may be worth saying a few words on the subject. There is usually very little choice of shape for the tanks in an aircraft; they are packed into any vacant space, no matter how inconvenient its shape. We shall see later that it may be necessary to pressurize the tanks slightly even in a pump-fed

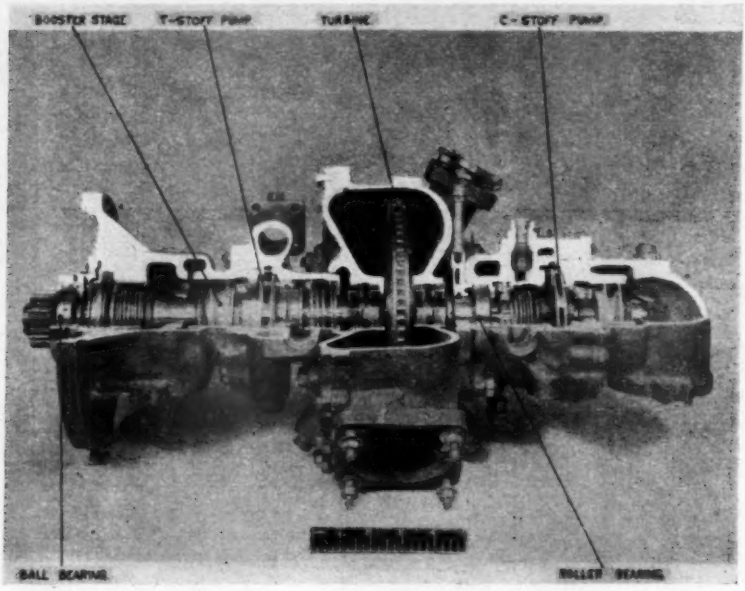

FIG. 3. Walter 109–509 A.Z. Turbo-Pump Assembly.

rocket, and in addition to the stress set up by the internal pressure, other stresses are produced by accelerations of an aircraft. The design of irregularly shaped tanks capable of standing such compound stresses is a problem that calls for individual treatment and no general principles can be laid down. In the case of pressure-fed rockets, stress conditions dictate that the tanks must either be spherical or cylindrical with domed ends, but this type of motor is most commonly used for assisted take-off units or missiles, into both of which these shapes can conveniently be fitted.

The choice of materials for fuel tanks is not critical, but the nature of the oxidizer fixes the material from which its tank can be made; two of the most common oxidizers (nitric acid and hydrogen peroxide) require tanks made of either stainless steel or pure aluminium, although it is possible to line tanks made of other metals with plastic. The third common oxidizer, liquid oxygen, is not so fussy, but owing to its low boiling point the tank must be efficiently lagged to reduce losses by evaporation. To give some idea of the order of this loss, the oxygen tank in one installation lost 8 per cent. of its contents per hour; improved lagging materials should at least halve this figure.

From the tanks the propellants will flow into the pumps, and in most pump-fed motors these will be driven by a turbine. In both aircraft and missiles weight has always to be kept to a minimum, and to save the weight of a gearbox impellers will usually be coupled directly to the turbine shaft, which is what

the designers of the turbo-pump shown in Fig. 3 have done. This means that the design of pumps and turbine should proceed hand-in-hand, and we usually find that it is more difficult to design pumps when they are to be directly driven than when they are driven at some convenient speed from an accessory drive gearbox on a gas turbine. We will consider a direct-coupled turbo-pump unit, then we can be reasonably sure that engine-driven pumps designed on the same principles will be successful.

First of all we must decide whether to use an impulse or reaction turbine. Generally speaking, for a given power an impulse turbine will be lighter and simpler to make (although not necessarily more efficient) than a reaction turbine, and for these reasons impulse turbines are nearly always used for rocket work.

The turbine is driven by a jet of gas issuing from a convergent-divergent nozzle, so some source of gas will be required. On the V.2 and on the Walter 109–509 motor the gas was a mixture of superheated steam and oxygen produced by the decomposition of hydrogen peroxide in a separate reaction chamber. If hydrogen peroxide is not used, a jet of fuel or water vapour can be produced by burning a small quantity of the main propellants in a separate chamber and cooling the combustion gases to a temperature suitable for the turbine by injecting extra fuel or water.

However the jet is produced, it will leave the turbine nozzle at a speed of over 2,000 ft./sec. Orthodox steam turbine theory shows that an impulse turbine will work at its maximum efficiency when $\frac{u}{v}$, the ratio of blade speed to jet speed, is about 0·5. This ratio is the most important design criterion for impulse turbines, and its effect on efficiency is shown in Fig. 4. We see then that for maximum efficiency the blade speed should be over 1,000 ft./sec., and a little arithmetic shows that to reach this speed a wheel 1 ft. in diameter would have to be run at 19,200 r.p.m. However, 2,000 ft./sec. is a conservative estimate of jet velocity and we may find that the blade speed should be nearer 1,500 ft./sec. for maximum efficiency. With present materials it is doubtful if a turbine disk could be designed that would not fly to pieces at this speed, particularly as it will be heated at its periphery.

There is another difficulty as well. A wheel 1 ft. in diameter would be unnecessarily heavy, and a 6-inch wheel would be much more convenient. However, the lowest optimum speed of such a wheel would be 38,400 r.p.m., and we shall see presently that this is an uncomfortably high speed for the pumps. We thus have the conflicting requirements, that high rotational speeds are desirable to give good efficiency and low turbine weight, but that the speed should not be too high for fear of overstressing the disk and causing trouble in the pumps. We cannot reduce the value of $\frac{u}{v}$ without losing efficiency, but if we run at a value of $\frac{u}{v}$ lower than the optimum we can improve on the efficiency of a single-stage turbine at that ratio by compounding the turbine. On the Walter turbine this was done very simply by using stationary guide blades to turn the gas leaving the moving blades and pass it through the wheel again

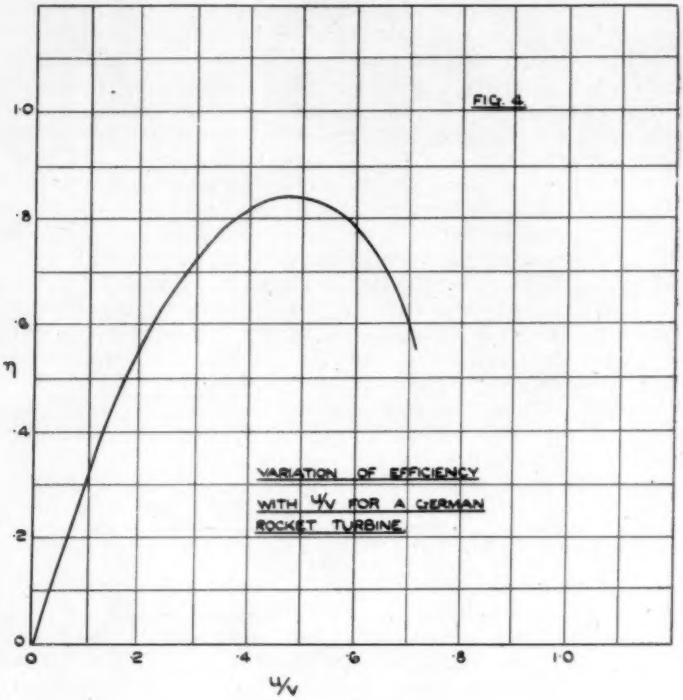

FIG. 4.

from the opposite side. This arrangement was virtually a two-stage turbine with only one wheel.

On the other hand it may be as well to ask ourselves if a high efficiency is really worth striving for, and the answer to this depends on the type of rocket motor to be designed. The turbine efficiency is reflected in the weight of propellants it consumes, and in the case of a missile or an assisted take-off unit it is the dry weight of the motor that must be kept to a minimum since all the propellants will be exhausted during the first minute or so and only the weight of the empty motor will remain. If this is so, it is not worth struggling after a high efficiency since the weight of propellants used by the turbine is only of secondary importance. But in an aircraft rocket motor the turbine propellants may have to be carried for some time before they are finally consumed, so it is obviously more important to keep their weight as low as possible. After weighing up all these considerations we can decide whether to use a simple or compound turbine, what the blade speed is to be, and what is the smallest diameter that will not give an unduly high pump speed. Once these points have been settled the detail design presents no real difficulties.

Turning now to the pumps, it is obvious from what has already been said that the pump speed will normally be high (above 10,000 r.p.m.), so centrifugal pumps are almost invariably used for rocket work. Before we can design the pumps we must know the speed at which they will run (which will already have been fixed by the turbine), the maximum flow they will be required to deliver (which is governed by the thrust of the motor and the specific impulse of the propellants), and the delivery pressure. The last figure will be equal to the sum of the combustion chamber pressure, the injection pressure drop and the pressure drop through the pipes and valves (including the combustion chamber cooling jacket), and a small allowance for adjusting the mixture ratio by putting hydraulic resistances in the pipelines.

Once the speed, flow, and pressure are determined we can calculate that most useful pump parameter, the specific speed. This is actually defined as the speed at which the pump would have to be run to deliver a flow of 1 gal./sec. against a head of 1 ft., and bearing this in mind you will see that it is connected with the shape of the impeller. To give this performance a thin, large-diameter impeller would have to be run at a lower speed than a broad, small-diameter one. We find in fact that there is an optimum impeller shape for a particular specific speed. The divisions are not clearly marked, but broadly speaking Fig. 5 shows the best shapes for various specific speeds.

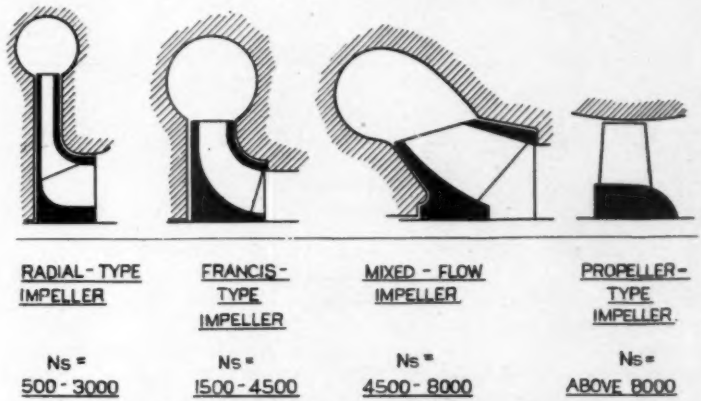

FIG. 5. Types of Centrifugal Pump Impeller.

Now it can be shown that the specific speed of a pump $N_s = \dfrac{N\sqrt{Q}}{H^{\frac{3}{4}}}$

where N = speed in r.p.m.
Q = flow in gal./min.
H = head in ft.

All these are known for our pumps so we can calculate their specific speeds and decide on the types of impeller to be used. Then, by using orthodox centrifugal pump theory, we can design the impellers themselves.

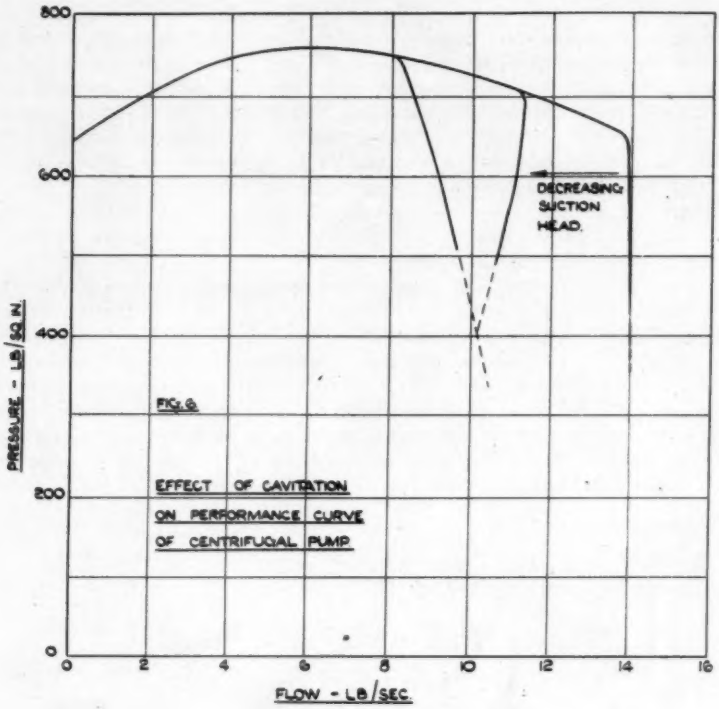

FIG. 6.

In using normal pump theory we ignore the effects of cavitation which occurs when the static pressure at a point inside the pump is less than the vapour pressure of the fluid. In these conditions bubbles will form in the fluid which will collapse again when they reach a region of higher pressure. Not only does the formation of vapour bubbles cause the pump to be unstable, but the collapse of the bubbles can be so violent as to cause physical damage to the pump. Fig. 6 shows the effect of cavitation on pump performance, while Fig. 7 shows the result of running an impeller for a long time under cavitating conditions.

The most useful parameter for deciding whether or not a pump will cavitate is the "suction specific speed," so called by analogy with the expression for specific speed already mentioned. The suction specific speed is

$$S = \frac{N\sqrt{Q}}{H_{sv}^{\frac{3}{4}}}$$

where H_{sv} is the net positive suction head, that is, the head above the vapour pressure measured at the pump entry. Experience has shown that S should

FIG. 7.

not normally exceed 13,000 or cavitation will occur. Now we have seen that it is desirable to run the pumps at a high speed if they are coupled directly to a turbine, so to keep S down to a reasonable value we should have to increase H_{sv}. This we can do by pressurizing the tank, but this scheme involves carrying gas to pressurize it and so increases the weight of the installation. Obviously it would be a great advantage if we could increase the limiting value of S, and a great deal of work has been devoted to the design of impeller inlets which permit this. One method, which was adopted on the Walter turbo-pump, is to fit an axial flow booster impeller immediately before the main impeller. The pump can then be run at a suction specific speed of over 13,000, and although cavitation will occur, its effect with this type of pump is less serious. Fig. 8 shows that instead of a sudden loss of head at the onset of

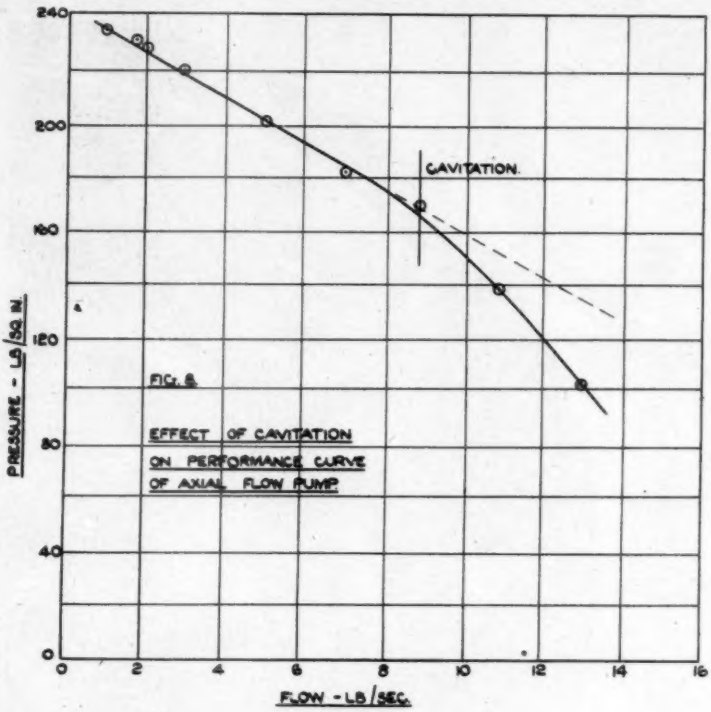

FIG. 8.

cavitation there is a gradual drop which is not marked enough to upset the performance of the rocket.

We will neglect for the moment the valves through which the propellants must flow on their way to the combustion chamber and consider the design of the combustion chamber itself, which includes also the injector and igniter. This can be a long and tedious business, as befits the hardest-worked component of the motor, and in this paper I can only give an outline of the processes involved.

The first step is to calculate the dimensions of the combustion chamber, and the dimension from which the others are derived is the throat diameter. There are various ways of getting this; the method described now gives quite good results although it involves one or two approximations.

First we write down the reaction equation which represents the burning of the propellants, thus

$$X\ C_8H_{18} + Y\ O_2 \rightarrow a\ CO_2 + b\ CO + c\ H_2O + d\ H_2 + e\ O_2$$

where a, b, c, d, and e are unknown. The constituents appearing on the right-hand side are those which we think are most likely to be produced. There may be traces of atomic oxygen or hydroxyl radical, but their inclusion does not

materially affect the answer and it complicates the solution immeasurably. Next we guess the combustion temperature, and by using equilibrium constants (which are known for various temperatures) and by equating numbers of atoms on both sides of the reaction equation, we can write down five equations from which we can find the unknown coefficients a, b, c, d, and e. Now we know the products of combustion, we can form a heat balance by saying that

heat of formation of products − heat of formation of propellants = heat available to raise products to combustion temperature.

We have all the data necessary to calculate these three terms, but if the two sides of the equation do not in fact balance we must guess another temperature and try again.

Eventually we guess the right temperature, and knowing the corresponding gas composition we can calculate the specific heats of the gas mixture and hence the ratio $C_p/C_v = \gamma$. This ratio will not change much throughout the expansion of the gases down to the throat, and knowing the initial temperature and pressure of the gases we can calculate their pressure and temperature at the throat by using the familiar thermodynamic relations

$$p_t = p_c \left\{\frac{2}{\gamma+1}\right\}^{\frac{\gamma}{\gamma-1}}$$

$$\text{and} \quad T_t = T_c \left\{\frac{2}{\gamma+1}\right\}$$

By the method described above we can determine the composition of the gases at this temperature and pressure and hence find their specific volume V. Now the velocity of the gases at the throat is

$$v_t = \sqrt{\frac{2g\gamma}{\gamma+1} RT_c}$$

which is known, and since

$$v_t = \frac{V}{A_t}$$

the throat area per pound of gas can be calculated and the necessary throat area found.

The combustion chamber volume can be found by using the parameter L^* or characteristic length, which is defined as the apparently arbitrary ratio

$$L^* = \frac{\text{volume of chamber}}{\text{throat area}}$$

In fact, however, L^* is closely connected with the time of stay of the propellants in the combustion chamber, and too low an L^* may mean that the propellants do not spend long enough in the chamber to burn completely. The characteristic length is best kept above 50 inches. This does not completely define the shape of the chamber, however, since a short squat chamber can have the same L^* as a long thin one. Usually the ratio of length to diameter lies between 1 and 2, but the shape chosen generally depends on the space available.

The last dimensions to be obtained are those of the expansion nozzle. Experience has shown that the optimum angle of divergence is about 30°, so we have only to decide what the outlet diameter is to be. Now the exhaust velocity and hence the specific impulse depend on the expansion ratio, and the nozzle can only be designed correctly for one expansion ratio. The choice of ratio usually depends on the conditions at which the motor will most often operate; an assisted take-off unit will expand the gases down to ground level pressure, while a climb boost rocket may be designed to work correctly at some altitude between 20,000 and 50,000 ft. Whatever ratio is chosen the exit area is given by this relation

$$A_e = A_t \sqrt{\frac{\left(\frac{p_t}{p_c}\right)^{\frac{2}{\gamma}} - \left(\frac{p_t}{p_c}\right)^{\frac{\gamma+1}{\gamma}}}{\left(\frac{p_e}{p_c}\right)^{\frac{2}{\gamma}} - \left(\frac{p_e}{p_c}\right)^{\frac{\gamma+1}{\gamma}}}}$$

We may find that this gives an inconveniently large outlet, in which case there is nothing for it but to use the largest possible outlet and to suffer the loss of performance due to under-expansion of the jet.

The problem of stressing a combustion chamber is tied up closely with the cooling of it. The usual way of cooling a chamber is to jacket it and circulate one of the propellants round the jacket before injecting and burning it. Not only do we want to prevent the chamber from burning out, but we also want to keep the mean wall temperature fairly low, since the strength of most metals falls rapidly with increasing temperature and we do not want the chamber to fail through over-stressing the wall.

It is no easy job to stress a complicated shape like a combustion chamber inner shell, and at best we can only use approximate methods. Even so, the calculation of wall thickness at various points along the chamber depends on the mean wall temperature at these points, and for the calculation of these temperatures we need to know the thickness of the metal. The best way of cutting this vicious circle is to plot a family of curves as shown in Fig. 9 in which the effect of thickness on wall temperature is shown for various coolant velocities. From these curves the stressman can choose a suitable wall thickness and temperature to give him the necessary strength, and this fixes the coolant velocity at this point.

In order to plot these curves, we write down three equations for the heat flow.

For the gas film inside the wall

$$Q = (\theta_g - \theta_a) \left\{\frac{x\,K_g}{D}\right\} \left\{\frac{\mu_g\,C_{pg}}{K_g}\right\}^{0\cdot355} \left\{\frac{v_g\,D\rho_g}{\mu_g}\right\}^{0\cdot8}$$

For the wall itself

$$Q = (\theta_b - \theta_a)\,\frac{K_w}{t}$$

For the coolant film

$$Q = (\theta_b - \theta_c) \left\{\frac{x\,K_c}{D}\right\} \left\{\frac{\mu_c\,C_{pc}}{K_c}\right\}^{0\cdot355} \left\{\frac{v_c\,D\rho_c}{\mu_c}\right\}^{0\cdot8}$$

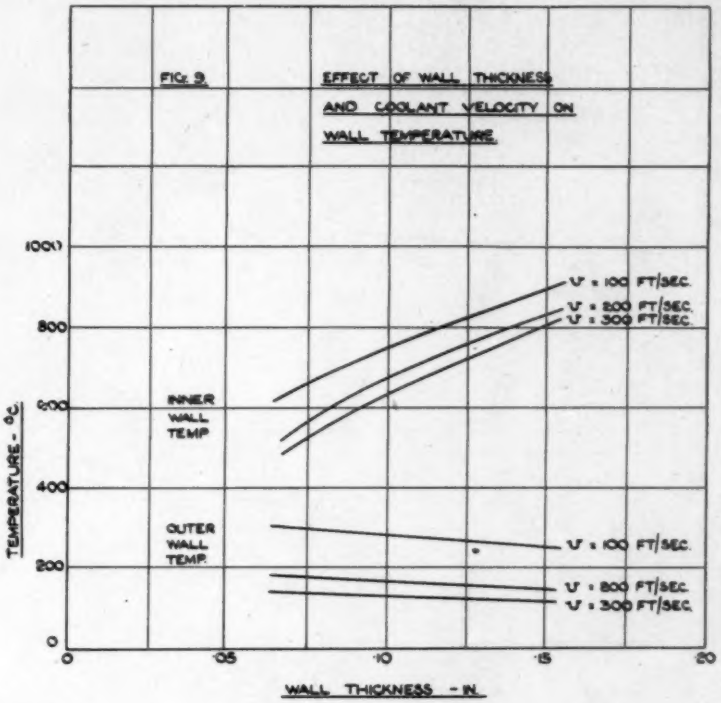

FIG. 9.

where C_p = specific heat at constant pressure
D = diameter
K = thermal conductivity
Q = heat flow per unit area
t = thickness of wall
v = velocity
x = constant
θ = temperature
μ = absolute viscosity
ρ = density
suffix a refers to hot side of wall
b refers to cold side of wall
c refers to coolant
g refers to gas
w refers to wall

Using these three equations we can calculate θ_a and θ_b for various values of t and v.

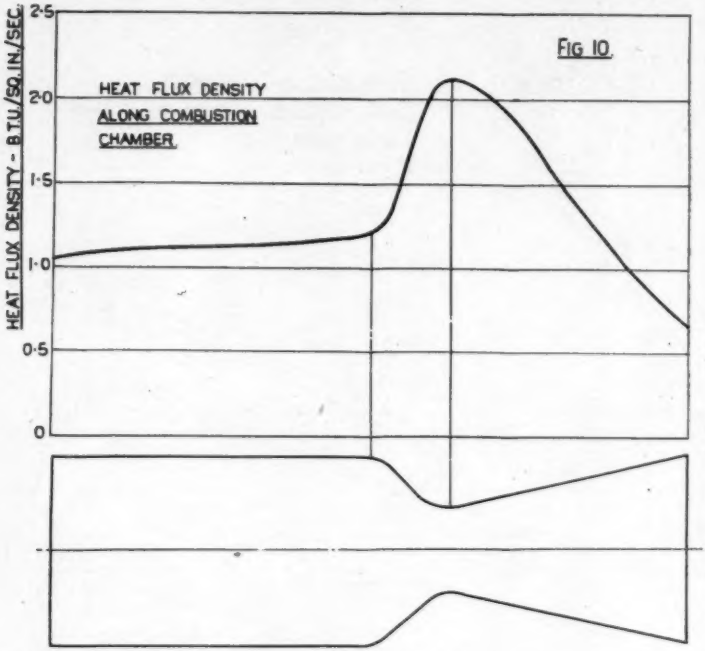

FIG. 10.

Now the value of Q varies considerably along the chamber and is greatest at the throat, as shown in Fig. 10. Accordingly we must plot families of curves like those on the previous diagram for various points along the combustion chamber, and hence we can calculate the wall thicknesses and coolant velocities for the whole chamber.

If our calculations indicate that the inner wall temperature will be excessively high in spite of the external cooling we may still be able to save the situation by using film cooling. To do this, small holes are drilled through the wall of the chamber just upstream of the area we want to cool. Fuel flowing through these holes is spread by the gas stream over the surface of the metal and evaporates, and in so doing cools the hot gases which would otherwise come into contact with the wall. At the same time the vaporized fuel forms a cool layer which further protects the chamber. It is possible to calculate the amount of film cooling required in a particular case, but trial and error usually gives equally good results.

An extension of this method is sweat cooling in which the whole (or at any rate some areas) of the inner shell of the combustion chamber is made of porous metal. Fuel percolates through this, picking up heat from the wall on its way, and evaporates when it reaches the gas side. This method is even less amenable to calculation than film cooling.

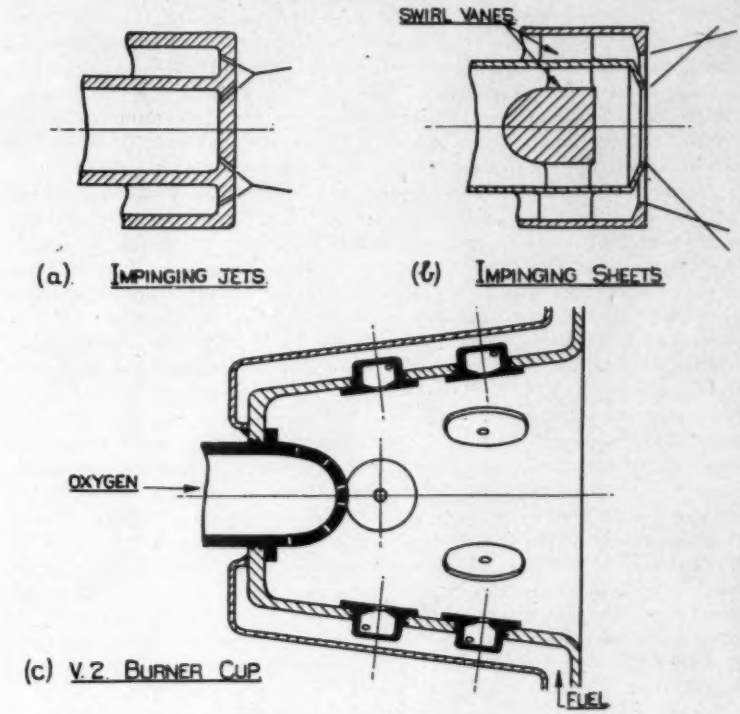

FIG. 11.

We come now to the other parts of the combustion chamber, of which the most important is the injector. The function of this is to get the propellants into a state suitable for burning, that is, finely divided and intimately mixed. There are many ways of achieving this result and some of them are shown in Fig. 11. The method chosen depends on the shape of the combustion chamber and the whim of the designer; theory cannot help much here. In fact it is now that the technician can help the designer, since a few runs on the test bed will very often show the superiority of one scheme over another which on paper seems just as good.

Lastly there is the igniter. If self-igniting propellants are used this is obviously unnecessary. If not, there are various methods of lighting them. The V.2 used a pyrotechnic device like a catherine wheel, which is all very well for single starts, but an aircraft rocket motor may have to be re-started in the air and a pilot flame of some sort must be provided. This is most easily done by using a pilot combustion chamber—a kind of off-shoot from the main chamber into which small quantities of the propellants are injected and lit by a sparking plug. The jet of flame issuing from this device then ignites the main

propellant stream. The design of the pilot combustion chamber proceeds along the same lines as that of the main chamber, but is not so critical since the igniter does not need to have a high performance and thus can be made to run at a lower combustion temperature.

We have now discussed all the major components of a rocket motor but we have said nothing about valves or control systems. Indeed it is difficult to generalize about this part of the motor since control systems vary enormously in complexity and valves often have to be developed to perform a special function. However, the design of rocket motor valves is not very different from the design of valves for ordinary aircraft hydraulic or fuel systems except that they are usually required to handle large flows. Moreover, it is important that they should respond immediately when they are required to act and that they should operate almost instantaneously. A delay of only a second or so in the opening of a valve might allow enough of one propellant to accumulate inside the combustion chamber to cause an explosion when the other propellant arrives. This particular fault is obviously undesirable in any motor, but generally speaking far greater emphasis must be placed on safety devices in a rocket that is to power a piloted aircraft than in a missile. In the latter case, the occasional failure of a component may result in a wastage of the missile, but a failure in an aircraft motor may cause loss of life. For this reason factors of safety should always be more generous in aircraft rocket design than in missile work, and all possible sources of trouble should be guarded by suitable safety devices. For instance, each step in the starting sequence of the "Snarler" oxygen-alcohol rocket is triggered by the previous one, so if, say, one pump fails to prime, the igniter will not start at all, or if the igniter does not light, the propellants cannot enter the combustion chamber. Such precautions may mean a heavier motor, but it can never be worth saving a few pounds of weight when the price that may have to be paid for it is the life of a pilot.

Finally, I should like to express my thanks to the Ministry of Supply for allowing me to use some of the material in this paper, to the Technical Director of Armstrong Siddeley Motors, Ltd., for allowing me to read it, and to those of my colleagues who have criticized or helped me in writing it.

THE SOCIETY'S NEW ADDRESS

As from May 12, 1952, the Society will move into its new offices at 12, Bessborough Gardens, London, S.W.1, and all further communications after that date should be sent there and not to 157, Friary Road, London, S.E.15, as hitherto.

The new address is situated very close to the Tate Gallery, and is only a few minutes' walk from Vauxhall Bridge. It may also easily be reached from Victoria by any bus passing along Vauxhall Bridge Road. A map giving fuller directions for the use of intending visitors will be given in a later issue of the Journal.

The Society's new telephone number will be TATe Gallery 9371.

THE FUNDAMENTAL BASIS OF POWER GENERATION IN A SATELLITE VEHICLE

By C. A. Cross, M.A.

ABSTRACT

This paper seeks to establish the basic design principles which must be followed in constructing an orbiting solar power generator. These demonstrate that this method of producing energy for an orbital base or satellite vehicle is fundamentally a sound and practical proposition. The engineering developments required to translate these principles into practice are not touched upon.

Introduction

The potentialities of an artificial satellite are widely recognised.[1, 2, 3, 4] Probably the first essay into this field will be a small unmanned rocket telemetering instrument readings to the earth,[2] which may then develop to the relaying of short wave radio messages such as television programmes,[3] and then to the establishment of manned bases for varied and extensive research.[1] Ultimately some form of orbital refuelling will lead to exploration of the other members of the solar system.

All these projects require an electrical power source. The special peculiarity of an artificial satellite is undoubtedly the very high cost of getting material from the earth to the satellite orbit. Power generation based on chemical fuels would be most uneconomic on this score, though the very high energy content of atomic fuels may offer one way out of this dilemma. Another possible solution is to use the sun's radiant energy, which is available in the orbit. This paper presents a theoretical analysis of solar generators upon which their basic design can be founded, and upon which conclusions may be based on the relative advantages of solar and atomic energy.

The Ideal Solar Generator

The conversion of the sun's radiant energy into electrical energy might be done in a variety of ways. A photosynthesis oxidation cycle might be possible, using plant life to convert the radiant energy into chemical energy as a first step. A thermopile might be arranged so that one set of junctions was heated by the sun, whilst the opposing set was cooled by radiation to space, so converting the thermal energy into electricity. The radiation might be used to heat the working fluid of a heat engine, and the resultant mechanical energy used to generate electricity. There are many of these possible schemes, and none of them can be dismissed as incapable of useful development. A survey of the present position[7] shows that the conventional boiler-turbine-condenser cycle is several times more efficient than the most promising competitor for the generation of power from solar energy on the earth's surface. These considerations apply with equal force in a satellite vehicle, and we shall accordingly limit ourselves to a treatment of this type of generator. In general terms it will consist of a heat engine of suitable form, with an efficiency limited by thermodynamic considerations, working between a high temperature boiler receiving solar

radiation, and a lower temperature condenser radiating waste heat away into space. Thus the ideal solar generator is shown diagramatically in Fig. 1, where all components (reflector, absorber, heat engine, and radiator) are assumed to be perfect.

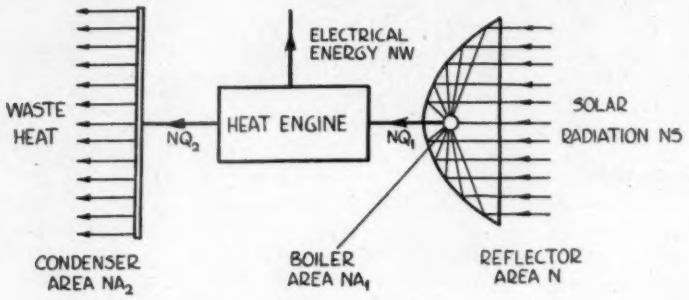

FIG. 1. The Ideal Solar Generator.

It will be seen that there are only two design variables, the boiler area (A_1) per unit reflector cross section, and the condenser radiating surface area (A_2) per unit reflector cross section. The performance will be determined by these factors, and the total area intercepting radiation (N) is simply a scale factor. In operating even a theoretically perfect generator of this kind the incident solar radiation is not completely converted into electrical energy for two separate reasons. Some energy is lost by re-radiation from the surface of the boiler, whilst some low grade thermal energy must be radiated from the condenser because of the inefficiency of even the most perfect heat engine. The proportion of these two losses will depend on the respective areas of boiler and condenser surface and upon the rate at which heat is allowed to flow through the heat engine. If only a very small fraction of the incident radiation energy is allowed to flow into the heat engine the boiler temperature will rise towards the value at which the re-radiated energy equals the incident energy flux, whilst the condenser temperature will fall towards absolute zero. Thus although the heat engine efficiency will approach unity the overall efficiency of conversion of incident radiation to useful work will be approaching zero. If heat is now allowed to pass through the heat engine at a higher rate the overall efficiency will improve. With continued increase in rate however the situation is eventually reached where the boiler temperature has so decreased and the condenser temperature so increased that the efficiency of the heat engine is approaching zero. Although a large part of the incident energy now passes through the heat engine most of it is radiated from the condenser surface and little appears as useful work. Qualitatively we can see that there will be an intermediate condition at which the efficiency reaches a maximum value. Quantitatively this overall efficiency η_o is given in terms of the boiler temperature T_1 and the condenser temperature T_2 by the following equations for a body at the earth's distance from the sun:

$$\eta_o = 1 - 4{\cdot}15 \times 10^{-11} A_1 T_1^4 - 4.15 \times 10^{-11} A_2 T_2^4 \quad .. \quad (1)$$

$$\eta_o = (1 - 4{\cdot}15 \times 10^{-11} A_1 T_1^4) \frac{(T_1 - T_2)}{(T_1)} \quad .. \quad .. \quad (2)$$

Given A_1 and A_2 these equations can be solved to give η_o and T_2 for any value of T_1. This has been done for the case $A_1 = A_2 = 1$ and the result plotted in Fig. 2. This shows that at $T_1 = 120°$ C. all the heat received is being radiated back towards the sun so that η_o is zero. The maximum overall efficiency possible is 7·65 per cent., when the boiler is at 95° C., and the condenser at − 18° C. The efficiency then falls again, reaching zero when $T_1 = T_2 = 58°$ C. This generator corresponds to the simplest possible case—a plane black body boiler surface exposed normally to the sun's rays, operating an ideal heat engine which exhausts to an equal area of black body surface condenser shaded from the sun's rays.

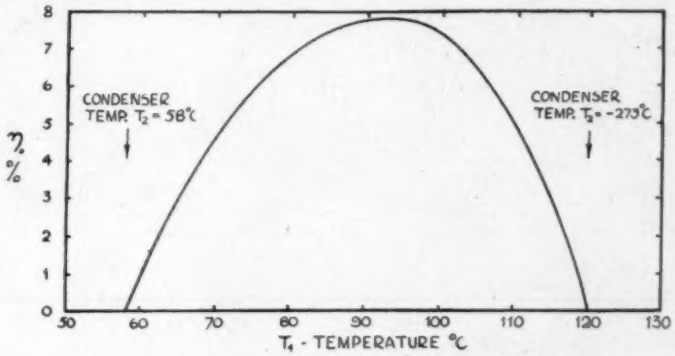

FIG. 2. Overall Efficiency as a Function of Boiler Temperature, for the case $A_1 = A_2 = 1{\cdot}0$.

The maximum overall efficiency can be increased by reducing A_1 and by increasing A_2. Concentrating the sun's radiation on to a smaller boiler surface by means of a reflector (reduction of A_1) cuts down the loss by re-radiation from the boiler surface. Enlarging the condenser radiating surface (A_2) reduces the condenser temperature and improves the performance of the heat engine so that less energy is lost as waste heat. Obviously both measures can be applied together to improve performance.

In determining quantitatively the effect of such changes upon the maximum overall efficiency it is not necessary to plot the equivalent of Fig. 2 for each combination of A_1 and A_2. We may derive equations from (1) and (2) giving directly the maximum efficiency and its associated temperatures. These are:

$$T_1 = 396\,(x/A_1)^{\frac{1}{4}} \quad .. \quad .. \quad (3)$$

$$T_2 = 396 \left[\frac{A_1^{\frac{1}{4}}(1-x)}{A_2\, x^{\frac{1}{4}}}\right]^{\frac{1}{4}} \quad .. \quad (4)$$

where x is given by the equation

$$\left[\frac{A_2 x}{A_1 (1-x)}\right]^{\frac{1}{4}} = \frac{1+3x}{3x} \quad .. \quad (5)$$

The maximum value of $\eta_o = \eta_{om}$ is then obtained by substituting these values of T_1 and T_2 in equation (1) The values of η_{om} T_1 and T_2 have been calculated in this way for a range of values of A_1 and A_2, and are presented below in Table I.

TABLE I

MAXIMUM OVERALL EFFICIENCIES AND ASSOCIATED TEMPERATURES

	$A_1 = 0{\cdot}001$	$A_1 = 0{\cdot}01$	$A_1 = 0{\cdot}1$	$A_1 = 1{\cdot}0$
$A_2 = 100$	$T_1 = 612°$ C. $T_2 = -208°$ C. $\eta_{om} = 90{\cdot}2\%$	$T_1 = 307°$ C. $T_2 = -199°$ C. $\eta_{om} = 83\%$	$T_1 = 111°$ C. $T_2 = -190°$ C. $\eta_{om} = 71{\cdot}3\%$	$T_1 = -14°$ C. $T_2 = -181°$ C. $\eta_{om} = 52{\cdot}7\%$
$A_2 = 10$	$T_1 = 757°$ C. $T_2 = -142°$ C. $\eta_{om} = 83\%$	$T_1 = 413°$ C. $T_2 = -129°$ C. $\eta_{om} = 71{\cdot}3\%$	$T_1 = 189°$ C. $T_2 = -110°$ C. $\eta_{om} = 52{\cdot}7\%$	$T_1 = 39°$ C. $T_2 = -105°$ C. $\eta_{om} = 28\%$
$A_2 = 1$	$T_1 = 947°$ C. $T_2 = -9°$ C. $\eta_{om} = 71{\cdot}3\%$	$T_1 = 547°$ C. $T_2 = 17°$ C. $\eta_{om} = 52{\cdot}7\%$	$T_1 = 282°$ C. $T_2 = 27°$ C. $\eta_{om} = 28{\cdot}0\%$	$T_1 = 95°$ C. $T_2 = -18°$ C. $\eta_{om} = 7{\cdot}65\%$
$A_2 = 0{\cdot}1$	$T_1 = 1087°$ C $T_2 = 242°$ C. $\eta_{om} = 52{\cdot}7\%$	$T_1 = 717°$ C. $T_2 = 259°$ C. $\eta_{om} = 28{\cdot}0\%$	$T_1 = 382°$ C. $T_2 = 182°$ C. $\eta_{om} = 7{\cdot}65\%$	$T_1 = 119°$ C. $T_2 = -8°$ C. $\eta_{om} = 1{\cdot}0\%$

The Real Solar Generator

Up to this point we have been considering a purely idealised model of a solar generator composed of perfect units, and we are now in a position to predict accurately the performance of such a machine. The efficiency of a real generator obviously could not be greater than that of the perfect one, but what are the exact nature of the changes which would result from the substitution of real components with non-ideal performance for the ideal ones?

An exact treatment of the real generator would require allowance for the following factors;

(1) The emissivity of the reflector is greater than zero.
(2) The emissivity of the boiler surface is less than one.
(3) The resistance to heat flow from the boiler surface into the working fluid is not zero.
(4) The heat engine is not a reversible machine.
(5) The generator is not 100 per cent. efficient.
(6) The resistance to heat flow from the working fluid to the condenser radiating surface is not zero.
(7) The condenser radiating surface has an emissivity of less than one.

All the imperfections from 3 to 6 may be regarded as deviations from the ideal conversion of heat energy into power, and may be measured by comparing the power generated by such a real set-up with the output of an ideal heat engine operated between the same temperature difference. This is known as an efficiency ratio, and in power station practice values of from 30 per cent. to approaching 50 per cent. of ideal performance are obtained (i.e., $E = 0{\cdot}3$ to $0{\cdot}5$). In a preliminary analysis of this kind it is only necessary to allow for this non-ideal nature of a turbo-generator set, because both reflectors and black body surfaces are available approaching quite closely to the ideal limits.

In addition to the inferior performance, the turbo-generator imposes certain practical limitations on the boiler and condenser temperatures which can be used. Thus the boiler temperature is limited to a value beyond which the turbine blades are liable to fail by plastic deformation. The condenser temperature lower limit is set by the vapour density becoming too small to be dealt with in a turbine of reasonable size. The necessity of using a real working substance also introduces certain temperature limits. Thus the plastic deformation limit is at present about 800° C. (ref. 6), whilst the working substance limits are about 400° C. and 20° C. for water, and 700° C. and 150° C. for mercury[5] (saturated vapour temperatures).

There is one further point which is of fundamental importance in considering the real generator. What happens to the power generated? It will be found that in general only a very small fraction leaves the satellite vehicle as light or radio waves. Neglecting possible short term energy storage essentially the whole quantity must leave as thermal radiation. Thus the power plant in practice is shown in Fig. 3.

This diagram represents the simplest complete energy diagram of a satellite vehicle, where all the thermal energy withdrawn from the boiler is radiated as waste heat from the condenser and working space surfaces. In practice the situation may become more complex. If any large part of the energy can be

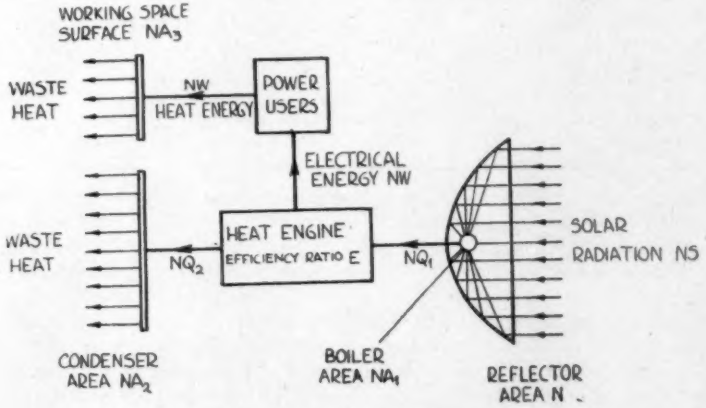

FIG. 3. The Real Solar Generator.

rejected at a temperature greater than that of the working space, then it may be economical to make special arrangements for this portion. Similarly some of the waste heat will probably be rejected at a lower temperature, to provide local cooling and refrigeration. Nevertheless to obtain a preliminary picture of the general nature of a manned orbital base we may assume a working temperature of 293° K., with all the electrical power dispersed as thermal radiation from a black body surface at this temperature.

On this basis we may set down the equations relating the area ratios, temperatures, and the overall efficiency for a non-ideal generator. We now find that it is not possible to obtain a set of equations giving directly the maximum overall efficiency and associated temperatures. The maximal values may however be computed, and this has been done for a turbo-generator working at half the efficiency of a reversible heat engine ($E = 0{\cdot}5$). The initial equations and the results are set out below in Table II.

TABLE II

MAXIMUM OVERALL EFFICIENCIES AND ASSOCIATED TEMPERATURES

(1) $\eta_{om} = 1 - 4{\cdot}15 \times 10^{-11} A_1 T_1^4 - 4{\cdot}15 \times 10^{-11} A_2 T_2^4$

(6) $\eta_{om} = (1 - 4{\cdot}15 \times 10^{-11} A_1 T_1^4) \dfrac{(T_1 - T_2)}{T_1} E$

(7) $\eta_{om} = 4{\cdot}15 \times 10^{-11} A_2 T_2^4$

The non-ideal Heat Engine, Efficiency Ratio $E = 0{\cdot}5$				
	$A_1 = 0{\cdot}001$	$A_1 = 0{\cdot}01$	$A_1 = 0{\cdot}1$	$A_1 = 1{\cdot}0$
$A_2 = 100$	$T_1 = 627°$ C. $T_2 = -163°$ C. $\eta_{om} = 43{\cdot}5\%$	$T_1 = 327°$ C. $T_2 = -165°$ C. $\eta_{om} = 39{\cdot}2\%$	$T_1 = 127°$ C. $T_2 = -166°$ C. $\eta_{om} = 32{\cdot}8\%$	$T_1 = -13°$ C. $T_2 = -170°$ C. $\eta_{om} = 23{\cdot}5\%$
$A_2 = 10$	$T_1 = 827°$ C. $T_2 = -81°$ C. $\eta_{om} = 39{\cdot}2\%$	$T_1 = 477°$ C. $T_2 = -82°$ C. $\eta_{om} = 32{\cdot}8\%$	$T_1 = 177°$ C. $T_2 = -83°$ C. $\eta_{om} = 23{\cdot}5\%$	$T_1 = 42°$ C. $T_2 = -85°$ C. $\eta_{om} = 12{\cdot}5\%$
$A_2 = 1$	$T_1 = 927°$ C. $T_2 = 70°$ C. $\eta_{om} = 32{\cdot}8\%$	$T_1 = 552°$ C. $T_2 = 67°$ C. $\eta_{om} = 23{\cdot}5\%$	$T_1 = 277°$ C. $T_2 = 57°$ C. $\eta_{om} = 12{\cdot}5\%$	$T_1 = 92°$ C. $T_2 = 0°$ C. $\eta_{om} = 3{\cdot}4\%$
$A_2 = 0{\cdot}1$	$T_1 = 1250°$ C. $T_2 = 330°$ C. $\eta_{om} = 23{\cdot}5\%$	$T_1 = 767°$ C. $T_2 = 300°$ C. $\eta_{om} = 12{\cdot}5\%$	$T_1 = 382°$ C. $T_2 = 205°$ C. $\eta_{om} = 3{\cdot}4\%$	$T_1 = 114°$ C. $T_2 = 50°$ C. $\eta_{om} = 0{\cdot}5\%$

The values of efficiencies and temperatures given in Table II have been plotted in a generally applicable form in Fig. 4, which shows contour lines of η_o, T_1 and T_2 plotted with A_1 as ordinate and A_2 as abscissa. On this graph the practical limits of boiler and condenser temperature set by the working substance are picked out for water and mercury. The areas enclosed and shaded thus form the regions in which water and mercury cycles may be employed. These are wedge shaped areas based in the low efficiency region, with their points reaching out towards higher efficiencies. It is evident that A_1 and A_2 are very closely defined if the overall efficiency is to be above 10 or 15 per cent. with either of these working substances.

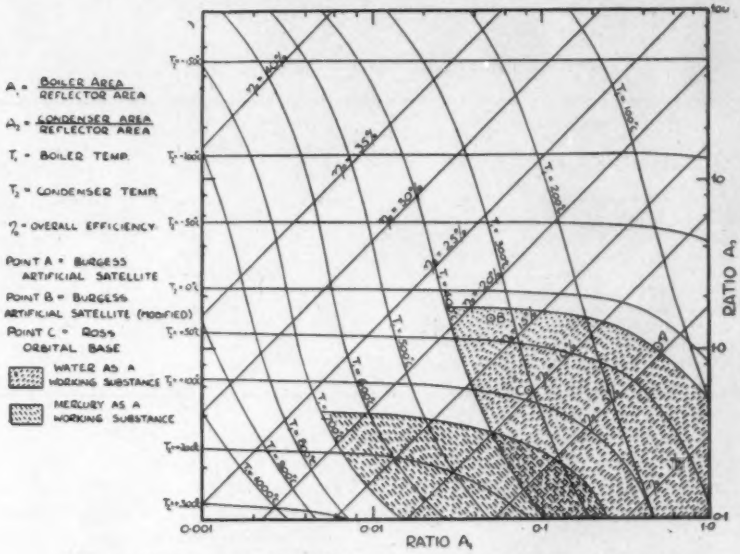

FIG. 4. Maximum Overall Efficiencies and Associated Temperatures.

Design Problems

To illustrate the use of Fig. 4 let us consider some specific design problems.

1. The Ross Orbital Base

This project requires a generating capacity of some 1,000 kilowatts. The following areas have been assigned.

Reflector cross section	..	2,900 sq. metres.
Boiler surface ..	..	250 sq. metres.
Back of reflector	..	3,000 sq. metres.
Working space surface	..	1,000 sq. metres.

There is no indication in the article of how the radiating surfaces behind the mirror are divided up between waste heat and condenser surface, but if we make the reasonable assumption that all the electrical energy generated is degraded to waste heat within the working space of the base, then a black body surface of 2,340 sq. metres is required to disperse it at a temperature of 293° K. This leaves 1,660 sq. metres for condenser surface, or $A_1 = 0{\cdot}086$, $A_2 = 0{\cdot}572$. This is point C, Fig. 4. At point C $\eta_{om} = 10\%$, $T_1 = 300°$ C., $T_2 = 90°$ C. Thus the maximum power generation possible would be about 400 kilowatts.

We may on the other hand calculate the areas required for mercury and for water cycles working at their limiting conditions, also for the combined mercury-water cycle.[5] These are shown in Table III.

TABLE III

SURFACE AREAS FOR THE ROSS BASE, SQ. METRES

Areas and Temperatures	Ref. 1	Water Cycle	Mercury Cycle	Combined mercury-water
Reflector cross section ..	2,900	3,250	3,100	2,300
Boiler Surface	250	88	15·5	7·6
Boiler temperature ..	300° C.	400° C.	700° C.	700° C
Condenser surfaces ..	1,660	5,700	1,550	4,400
Condenser temperature ..	90° C.	20° C.	150° C.	20° C.
Working Surface	2,340	2,340	2,340	2,340
Working surface temperature	20° C.	20° C.	20° C.	20° C.
Maximum overall efficiency, %	10·0	22·0	23·0	31·0

It must be emphazised that under no circumstances could the original design be operated at more than 10 per cent. overall efficiency. No assumptions about the nature of the working fluid are involved in this conclusion, and the use of an efficiency ratio of 0·5 is open to criticism as an optimistic estimate rather than as a pessimistic value, for this performance is only approached by large installations operated with the most rigid economy. Table III shows that the reason for this poor performance is the large boiler surface, with associated high losses by re-radiation. The calculated optimum boiler areas are all much reduced, but the heat transfer rates are still within the limits of current boiler practice, except possibly in the combined cycle. It is evident that the mercury cycle operating at its maximum efficiency would fit the requirements of the orbital base provided the boiler tube area were suitably reduced. The radiating surfaces of the base are not sufficiently large to cope with the total heat flux at the lower temperatures involved in the water cycle or the combined mercury-water cycle.

2. The Burgess Artificial Satellite

Here the design is quite closely specified, requiring the production of 1·5 kilowatts of modulated short wave radiation, plus 0·1 kilowatts for ancillary services. The author suggests an overall efficiency of 10 per cent. based on a gas cycle, and arrives at the following areas:

Area exposed to radiation = 17·5 sq. metres.
Boiler area = 8·75 ,,
Condenser area = 18·0 ,,

or $A_1 = 0{\cdot}5$, $A_2 = 1{\cdot}0$.

Consulting Fig. 4 we see that the maximum efficiency obtainable with these area ratios (point A) is only 5·5 per cent., so that the proposed design can only produce about 1·3 kilowatts of electrical energy.

The reason for this inadequacy is not however fundamental. As a breakdown provision the author has arranged to store his high temperature working fluid in a tank with a black body surface exposed to the sun. This black body surface counts as boiler area, and the efficiency is limited because of the high losses by re-radiation from it. By arranging this tank to be completely silvered we obtain the result:

Mirror area	=	12·0 sq. metres.
Boiler area	=	0·6 ,,
Condenser area	=	18·0 ,,

or $A_1 = 0{\cdot}05$, $A_2 = 1{\cdot}50$.

This modification gives an efficiency (point B) of 17·5 per cent. so that an adequate 2.8 kilowatts can be generated. The reduction in cross-section intercepting sunlight is more than counterbalanced by eliminating the radiation losses from the hot storage tank.

It is evident that neither author has appreciated the importance of minimising the heat lost by radiation from the boiler surfaces, and that when this defect is remedied the proposed designs are operable in the manner intended.

REFERENCES

(1) H. E. Ross, "Orbital Bases." *B.I.S. Jnl.*, **8** (1), January, 1949.
(2) E. Burgess, "The establishment and use of artificial satellites." *Aeronautics*, Sept., 1949.
(3) A. C. Clarke, "Extra-terrestrial relays." *Wireless World*, Oct. 1945.
(4) H. Oberth, "Stations in Space." *Wege zur Raumschiffart*, Part IV, Chapter 20.
(5) H. N. Hackett, "Mercury cycle power generation." *Gen. Elec. Rev.*, Oct. 1950, p. 14.
(6) T. W. F. Brown, "Some factors in the use of high temperatures in gas turbines." *Inst. Mech. Eng. Proceedings*, 1950, **162**, 167.
(7) Eugene Ayres, "Power from the Sun." *Scientific American*, August 1950, p. 16.

NOMENCLATURE

N	=	Total reflector cross section normal to sun's radiation.
NA_1	=	Boiler surface area.
NA_2	=	Condenser radiating surface area.
NA_3	=	Working space surface area.
S	=	Solar constant.
NQ_1	=	Heat extracted from the boiler per second.
NQ_2	=	Heat rejected to the condenser per second.
NW	=	$N(Q_1 - Q_2)$ = Useful work (electrical energy) obtained per second.
T_1	=	boiler surface temperature.
T_2	=	condenser surface temperature.
η_o	=	overall efficiency = W/S.
η_{om}	=	maximum overall efficiency.
x	=	convenience factor
E	=	Efficiency Ratio.

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CAREERS IN ASTRONAUTICS

By A. V. Cleaver, A.F.R.Ae.S.

The British Interplanetary Society now receives, with increasing frequency, enquiries on the above subject from various classes of people, all of whom share at least one attribute: they have become intensely interested in the possibility of space flight, and want to know how they can best set about the task of devoting their working life to help in its achievement.

Most of our enquiries come from youngsters, between the ages of nine and nineteen, who are naturally concerned about their initial choice of a job, and a course of training for it. A surprising additional number, however, come from older individuals who are apparently quite anxious and willing to change their whole mode of life, if only they can obtain the chance to work on the subject that interests them most. The B.I.S. is always anxious to help its members in any way reasonably possible, and so various Council members have, in the past, devoted quite a lot of time to answering all enquiries of the above nature individually. Now, however, it is hoped in this short article to deal with all the relevant points which repeatedly crop up in the letters we receive from astronautical aspirants of all age-groups and all backgrounds.

In the first place, it should be clearly realized that, at the present time, there can be no such thing as a career specifically and accurately described as "astronautical," for the simple and obvious reason that no one is yet designing and building spaceships. The term "astronautical engineer" cannot yet have the same significance as "aeronautical engineer," therefore, although one day we feel sure it will have. Nor is it yet possible to specialize at any college in rocket engineering, though most modern courses in, say, aero-engine design will pay some attention to the rocket motor. This state of affairs is an entirely logical one, and must be expected to persist for many years to come. Space flight will eventually *evolve*—after a long and gradual process—from progress made (for quite different purposes) in other branches of science and technology.

The men who designed and constructed the first aircraft had not been trained as aeronautical engineers, for the similar reason that, in the nineteenth century, such a term was meaningless. They had gained their early experience as mechanical or marine engineers, or in some other related field; in this connection it must be noted that personal enthusiasm and determination count for a lot. (Whatever a man's background, if he *really* wants to do something, there is usually a way by which he can accomplish it.) Along similar lines we may expect the designers and constructors of the first spaceships to be drawn from the ranks of such industries as aviation. In particular, they are likely to have worked for years in such fields as the application of rocket propulsion to aircraft and guided missiles, and in the development of such vehicles themselves.

In the second place, it is worth emphasizing once again something which has frequently been stated by this Society—the subject of astronautics, even in its purely scientific aspects, embraces an extremely wide range of subsidiary, but all-important, subjects. So far we have mentioned only the engineers.

However, physicists and chemists and metallurgists also occupy key positions in rocket research; so do mathematicians and so—especially in the future—will astronomers. Specialists in electronics are obviously also vital to the progress of rocket flight, in connection with guidance and control problems; when we get the first "ion rockets," they will probably combine with the nuclear physicists to become the most important members of the design and development team working on the "rocket" power plant itself!

Thus a man might enter almost any field of science or technology and still contribute indirectly towards the eventual achievement of space flight. Within the next generation his contributions are likely to become even direct ones, with more obviously vital connections to the basic theme of rocket flight. The range of subjects involved is really even wider than has so far been indicated; for example, the medical man, beginning by specializing in aviation medicine, will have a great deal to do with the achievement of the first flights out into space.

Let us return from these generalizations to the problems of the mid-twentieth century boy who wants to be "something to do with rockets"—eventually, "something to do with spaceships." Well, obviously he should specialize at school in scientific and mathematical subjects, and pursue such practical hobbies as he can—building model aircraft or radio sets or telescopes, and so on. It is as well, however, that he should not completely neglect other things! Quite apart from the important consideration that the narrow specialist is usually a rather dull fellow, modern languages are useful (because all rocket research is not, and never will be, done entirely in the English-speaking countries). Also, any scientist or engineer must be capable of writing a clear report in good, simple English (or whatever else his native tongue may be).

Having specialized in technical subjects at school, our hypothetical youth should then set about entering one of the recognized existing branches of science or technology. Headmasters—and even parents!—should be capable of giving advice, in particular cases, on this sort of thing; they will know, or can find out, about such matters as available scholarship or apprentice training schemes in particular districts.

For a career in pure science—physics, chemistry or mathematics—at least three years at a University, leading to a recognized degree, is desirable after leaving school. In engineering, two broad avenues are available as alternatives. Either the student may enter a University straight from school, and take an engineering degree, gaining practical experience in short courses at factories during vacations, and (preferably) concluding with one or two years' practical apprenticeship at an engineering works after leaving college. Alternatively, he may go straight from school into a recognized apprenticeship scheme with some industrial firm. In the latter case, he will obtain his theoretical training from part-time day and evening courses which lead either to an external University degree, or the award of a Higher National Certificate in engineering, or to the passing of the examinations of one of the professional institutions (e.g., the Institution of Mechanical Engineers or the Royal Aeronautical Society). Such a course usually lasts five years. Another

compromise solution sometimes adopted is the "sandwich scheme," in which the apprentice-student does one year in the works, one year at college, and so on.

In England, various schemes of financial grants, to aid poorer students with University or apprenticeship training, are available. Most big engineering firms operate well-organized apprenticeship schemes, with time off for study at courses run in association with local technical colleges, and with pay for their apprentices during training.

As we have said earlier, the future spaceship will evolve gradually from the rocket aircraft and guided missile of to-day, so our "astronautical aspirant" might do well to consider aeronautics as the path through which he attains his ambition. If he studies the news columns and "situations vacant" advertisements in such periodicals as *Flight* and *The Aeroplane* (in England), he will soon know which firms are engaged on such work. At the present time the prospects for employment in these fields are, of course, very good; any young man who has done well on a course of training of any of the types described above should have little difficulty in securing a job on some aspect of rocket work. Apart from the firms involved, there is of course the Scientific Civil Service, with its research establishments such as Farnborough and Westcott—at the R.A.E., Farnborough, an apprenticeship scheme is run at the establishment itself. If the youngster in question has specialized in pure science rather than engineering, he may find more opportunities at an official establishment than in industry, but a choice is still likely to be open to him. It takes all sorts to make a world—not least a world in which new technical devices are being created!

Some cautious parents may question whether all the above opportunities do not rest rather precariously on the present troubled world situation. In some measure they do; most of the rocket research now going on would be, at least, drastically curtailed if a real peace suddenly broke out. It seems most unlikely, however, that it would be completely stopped. Even before we see "Earth satellite vehicles" in demand as television relay stations, there are *some* peaceful uses for rockets—as high altitude research vehicles and for the assisted take-off of civil aircraft, for example. Aviation as a whole would not collapse in a world really at peace, and (in any case) rocket technology is not so very specialized that its experts could not, perhaps temporarily, find work to do in other aeronautical spheres, or even in older branches of engineering and science.

From what has been said it should be apparent that the older man wanting to enter the field of rocketry will be faced with very different problems, according to his particular background. If he is a technical man, with a good training and experience behind him, then he too (at the present time) should find relatively little difficulty in achieving his desire. One could not offer him better advice than to watch the advertisements in the aeronautical press over a period, and make suitable applications. Or he could write to any of the appropriate firms or official establishments, stating his ambitions and qualifications quite clearly; for example, if he were an electronics specialist, he could write to any of the big radio firms, asking if they could offer him employment on missile guidance projects. If they were not engaged on such work they would

say "No": if they were, then they might say "Yes"! Most organizations much prefer to employ people who really *want* to do the sort of work on which they are actually engaged.

On the other hand, if the individual concerned is, say, a bank clerk in his thirties, then the position is much more difficult, if not impossible. Without a very serious drop in salary and status, such a drastic change of job (even if the opportunity occurs) can very rarely, if ever, be negotiated after the early twenties are passed. Imagine the position in reverse—if an engineer or physicist wanted to take up banking! (Curious that one has never heard of such an instance. . . .)

To borderline cases of the above kind—to very young men who have realized, perhaps *just* in time, that they should embark on the career they really want—one might suggest that they try to make the change in stages. They might first attempt, for example, to secure *any* sort of technical job, and begin some course of theoretical evening studies at the same time. After a series of such changes, they might finish up with what they want, but such a course should not be adopted lightly, without due regard for all the consequences, or in the mistaken impression that all there is to rocket science and engineering is an interest in its more glamorous aspects. Don't forget the blood, toil, sweat and tears—the years of gaining experience and study for examinations!

All of which points to the desirability of choosing the right career for yourself in the first place (younger readers please note), but, to all who choose astronautics as their aim, whoever they may be, the B.I.S. says—"Good luck!"

SOLAR SYSTEM NOTES—3

By Patrick A. Moore, F.R.A.S.

The first interplanetary objective is, of course, the Moon; next "on the list" are Venus and Mars, and indeed these three bodies seem the only worlds in the Solar System suitable for colonization. On the other hand some of the Minor Planets, or "Asteroids," may eventually be utilized as refuelling stations, and some interesting members of the group have recently been under study in America.

The first asteroid, Ceres, was discovered as long ago as 1801; its existence had long been guessed at on account of "Bode's Law," a so-called relationship of planetary distances—now generally assumed to be mere coincidence—which indicated that there should be a body occupying the wide gap between the orbits of Mars and Jupiter. Four more were added within the next six years; the next discovery did not take place until 1845, but others followed thick and fast, and to-day the known asteroids are embarrassingly numerous. The vast majority have orbits lying entirely between those of Mars and Jupiter, and as all the asteroids are very small (Ceres, the largest, is only 500 miles across), none can retain any trace of atmosphere.

However, there are some asteroids whose orbits take them away from the

main swarm. The "Trojan" group consists of a dozen or more asteroids circling at about the mean distance of Jupiter (483 million miles), but of more interest to us are the so-called "Earth-grazers," which invade the inner regions of the Solar System and sometimes come very close.

The best-known of these is Eros, discovered in 1898. It can approach to within 14 million miles of the Earth, and as it is at least fifteen miles in diameter —though irregular in form—it can then be seen with comparatively modest telescopes. Observations made of it at the last close approach, that of 1931, enabled Sir Harold Spencer Jones to correct the value of the astronomical unit (distance from the Earth to the Sun) to the now-accepted figure of 93,009,000 miles. The next close approach will not take place until 1975.

Two real "Earth-grazers" were discovered in 1932. The first, Amor, came within 10 million miles of us; but it is less than five miles in diameter, and therefore very faint. As these tiny bodies are susceptible to every minute perturbing influence, their orbits are very difficult to compute with precision, and it was a great feat to re-discover Amor in 1940. The second asteroid, Apollo, came within 7 million miles, but is even smaller than Amor, and has not been seen since. Next came Adonis, which passed within 1½ million miles in 1936. Even more startling was Hermes, discovered in 1937, which brushed by at a mere 485,000 miles, roughly double that of the Moon—certainly the narrowest escape we have yet had, though it must be admitted that astronomers were not in the least alarmed! It is true that Hermes, with a diameter of one mile and a mass of three billion tons, would cause great destruction if it did happen to hit us; the famous Siberian meteorite of 1909, which wrecked a vast area, was certainly not so large. Fortunately, however, the chances of a direct collision are vanishingly small. The latest "Earth-grazer" was discovered by Wirtanen, at Lick, in February, 1950; it can approach to within 5½ million miles, but it too is very minute.

Perhaps the most interesting of all these unusual asteroids is Icarus, discovered in June, 1949, by Dr. Baade with the 48-inch Schmidt telescope on Palomar Mountain. Like most of the "Earth-grazers" it has a comparatively eccentric orbit, more like that of a comet than that of a major planet; when discovered it was eight million miles distant and can never approach closer than four million, so that in this respect it is not to be compared with Adonis and Hermes. But it is unique inasmuch as its perihelion (closest point to the Sun) lies inside the orbit of Mercury—a bare 21 million miles from the solar surface. Never before has an asteroid been known to invade these torrid regions. Let us hope that it can be kept under observation, and not lost as Apollo has been.

Of all the worlds in the Solar System, Icarus is probably the most uncomfortable. Airless and totally unprotected from the solar rays, its "summer" temperature must be in the region of a thousand degrees Fahrenheit, and it is even possible that it becomes hot enough to glow a dull red. Two hundred days later, when it has reached its aphelion outside the orbit of Mars, the temperature will have dropped far below zero. Utilization of the more conventional asteroids may well be accomplished within the next few centuries; but it is safe to say that Icarus, alternately baked and frozen, will be left severely alone!

FORMATION OF BRANCHES

In view of the keen interest in and support for the two present branches of the Society, the Council has felt it opportune to lay down certain main lines of policy and guidance on the formation of branches generally for use by other members who might be interested in exploring such a possibility.

In general, the Council approves of the formation of branches only where it is satisfied that there is adequate support for it in the area, and the minimum requirement is usually therefore that the branch be assured of a local membership of about 20 members, one at least of whom must be a Fellow.

All branches are largely autonomous, but under the general direction of the Council, and must be prepared to manage their own affairs almost entirely. This usually involves arranging a programme of lectures and other activities, and although the Council are frequently able to help in this, the number of demands made upon them are already very great and cannot be increased to a very large extent.

In these early formative years of the Society, it cannot be expected that any Branch can be self-supporting even though it may obtain donations from local members. The greater part of the funds must therefore come from a Council grant, and in determining this point, the Council will have regard not only to past activities but to future potentialities.

The amount is normally sufficient to cover the cost of meetings and normal administrative expenses, but little is left over for other possible activities, e.g. the formation of a branch library.

In certain special cases, the Council is prepared to make an additional grant for some specified purposes, but these cases are naturally judged on their individual merits.

Where some informal organization is intended which, e.g. may involve holding merely one or two occasional meetings, the Council will be prepared to consider such requests as they arise.

It is open to every member to attend any meeting of the Society at any branch he wishes, but the local branch secretary should be advised by members who would like to be kept informed of all activities in their area.

At a recent meeting of the Council in London, to which branch representatives were invited for consultation, the following bye-laws were approved to govern the activities of branches as from January 1, 1952.

BRANCH BYE-LAWS

Membership

1. A Branch Member shall be any member of the Society who notifies the Branch Secretary that he wishes to take part in Branch activities.

2. All members shall be entitled to receive details of Branch activities and to take part in these activities.

3. Members may introduce visitors to meetings of the Branch, subject to seating accommodation being available.

Branch Committee and Officers

4. The affairs of the Branch shall be governed by a Committee of nine members (one of whom must be a Fellow), or such other number as may be determined by the Branch in General Meeting.

5. Each Member of the Committee shall have one vote.

6. (*a*) The Committee shall be elected by the Branch at each Annual Meeting, and shall hold office until the next Annual Meeting.

(*b*) At the first and each subsequent Annual Meeting, one third of the Committee for the time being, or if their number is not a multiple of three, then the number nearest one third, shall retire from office.

(*c*) The Members of the Committee to retire in every year shall be those who have been longest in office since their last election, but as between persons who were elected on the same date, those to retire shall (unless they otherwise agree among themselves) be determined by lot.

(*d*) The Branch at the meeting at which a Member of the Committee retires in the manner aforesaid may fill the vacated office by electing a person thereto, and in default the retiring Member of the Committee shall, if offering himself for re-election, be deemed to have been re-elected, unless at such meeting it is expressly resolved not to fill such vacated office or a resolution for the re-election of such person shall have been put to the meeting and lost.

(*e*) No person other than a retiring Member of the Committee shall be eligible for election to the Committee unless there shall have been deposited with the Branch Secretary not less than twenty-one clear days before the Annual Meeting a notice of nomination in writing signed by two members qualified to attend and vote at such Annual Meeting, and also notice in writing by the person nominated of his willingness to be elected.

(*f*) The Committee shall have power to fill any casual vacancies, but such persons shall hold office only until the next following Annual Meeting, and shall not be taken into account in determining the Members of the Committee who are to retire by rotation at that meeting.

7. At the first meeting after their election, the Committee shall elect from among their number a Chairman, Secretary, and such other officers as they deem necessary from time to time.

8. The Chairman shall preside at all Committee and General Meetings at which he is present.

9. The Secretary shall be responsible for:—

(*a*) Submitting annual reports of Branch activities to the Council.

(*b*) Providing an annual statement of accounts and balance sheet made up to 30th September in each year in a form approaching that used by the Society as nearly as possible, to be sent to the Secretary of the Society as soon as possible after that date.

(*c*) To give notice of all meetings and to prepare agenda, minutes, etc.

Meetings

10. An Annual Meeting shall be held by the Branch at the conclusion of each yearly session, for the purposes of:—

(*a*) hearing a report of the Committee on the activities during that year.

(*b*) electing a Committee for the ensuing year;

(*c*) general discussion on Branch affairs.

11. The quorum for General Meetings of the Branch shall be five, and for Committee meetings, three.

Voting

12. At General Meetings of the Branch each member present shall have one vote whether on a show of hands or by poll.

13. Any two members personally present may demand a poll, such poll to be taken as decided by the Chairman of the Meeting.

14. In the case of an equality of votes, the Chairman shall have a second or casting vote.

Library

15. A Library may be maintained by the Branch and rules for its operation laid down by the Committee.

Finance

16. The Branch shall open a Banking Account in its own name for the purpose of therein depositing its funds, and such account shall be operated by cheques signed by the Branch Secretary and one other Member of the Committee.

General

17. These Bye-Laws shall operate as and from the 1st day of January, 1952, except insofar as they may subsequently be amended, cancelled or added to by Resolution of the Council of the Society, in which case they shall operate as amended from the date of such Resolution.

18. Any dispute concerning the interpretation of these Bye-Laws shall be decided by the Council, whose decision shall be final.

(Attention is also drawn to Nos. 33–36 of the Society's General Bye-Laws which relate to Branches—see pages 379–380 of the 1950 *Annual Report*.)

NOTES AND NEWS

Journal Publishing Date

Up to the present the *Journal* has been published at the *end* of the month of issue, i.e. the March *Journal* appeared on or near 31 March, and so on. This has been necessitated largely by printing arrangements, but it has caused a great deal of confusion in the minds of newer members, and occasioned much unnecessary correspondence and enquiry.

The Council has always felt it would be desirable if the *Journal* could be issued at the beginning of the month, and we are very pleased to announce that this has now been agreed with our printers.

Accordingly, for the future the *Journal* will appear usually in the first week of the month of issue, some slight reservation still being necessary about the exact date, as occasional difficulties in production sometimes arise.

Interplanetary Radio

The March, 1952, issue of *Astounding Science Fiction* contains a very interesting paper by "J. J. Coupling" (actually the well-known American electronics expert J. R. Pierce) on the use of radio for astronautical purposes. This paper, entitled "Don't Write: Telegraph!" estimates the powers needed for various types of interplanetary service. The author quotes the following figures for the three main types of communication:

	Bandwidth (c/s.)	Signal/noise power ratio	Min. power needed at receiver (watts)
Teletype	170	100	$6{\cdot}8 \times 10^{-16}$
Telephone	4,000	10,000	$1{\cdot}6 \times 10^{-12}$
Television	4,000,000	10,000	$1{\cdot}6 \times 10^{-9}$

(These figures agree very closely with those given in A. C. Clarke's paper "Electronics and Space-Flight," *J.B.I.S.*, **7**, March, 1948.)

Assuming the use of 3 cm. waves, and antenna 50 ft. in diameter, the following powers would be needed for Earth-Moon and Earth-Mars links:—

	Moon	Mars in conjunction	Mars at opposition
Teletype	$.11 \times 10^{-6}$	0·24	4·0
Telephone	26×10^{-3}	570	9,300
Television	26	570,000	9,300,000

(Mars at opposition: Power in watts)

Some striking results are arrived at regarding the possibility of *interstellar* radio when our communication techniques have been developed to the theoretical limit. For a very narrow bandwidth (10 c/s.) teletype service, a signal/noise ratio of unity, a wavelength of 1 cm., and antenna 100 ft. in diameter, the power needed to send a signal to Alpha Centauri is the astonishingly low figure of 650 watts! A slight increase of power (to about a kilowatt!) might be needed to avoid quantum effects, and with a suitable encoding system messages could be transmitted at the rate of about one word a second.

Visit to an Observatory

Mr. P. A. Moore, who has a 12-inch reflector at his home at East Grinstead, has very kindly offered to show the future objectives of the Society to interested members.

The best time for observation of the Moon is when the phase is between new and first quarter (after which it is not visible with the reflector owing to the presence of obscuring trees).

East Grinstead can be reached by Green Line coach from Victoria, these running every half-hour until fairly late. Members who would like to see the Moon and planets should write direct to Mr. Moore at "Glencathara," Worsted Lane, East Grinstead, Sussex.

T. Bernard Hall Prize

An interesting sign of the times is the recent award of the T. Bernard Hall prize by the Institution of Mechanical Engineers to Mr. L. N. Thompson (Fellow of the B.I.S.) for his paper, "Fundamental Dynamics of Reaction-Powered Space Vehicles."

The prize is awarded annually for a paper dealing with research and invention, and this is probably the first time that a senior Institution has awarded a prize for a paper dealing specifically with space-flight.

Book of the Month

We congratulate our Chairman for the selection of his book *The Exploration of Space* by the American "Book of the Month Club." We understand that it is non-fiction choice for July and publication date is provisionally fixed at 18 June. Mr. Clarke will be in the United States most of this summer and hopes to meet as many members of American rocket and astronautical organizations as possible.

ABSTRACTS

Edited by J. HUMPHRIES

Abbreviations of titles of journals were given in the May, 1950, issue of the *Journal*, and addenda have appeared in subsequent issues. The following is a further addendum to the list.

Amer. Helicopter.	American Helicopter.
J. Amer. Soc. Naval Engrs.	Journal of the American Society of Naval Engineers.
J. Aviation Medicine.	Journal of Aviation Medicine.
J. Inc. Plant Engrs.	Journal of Incorporated Plant Engineers.
Math. Gaz.	Mathematical Gazette.
Pacif. Rocket Soc. Bull.	Pacific Rocket Society Bulletin.
Riv. Maritt. Suppl. Tecn.	Rivista Marittima, Supplementa Tecnica.
U.S. Naval Inst. Proc.	U.S. Naval Institute Proceedings.

Many of the articles noted are available on loan to members resident in the British Isles. Requests should be addressed to J. Humphries, 97, Churchill Avenue, Southcourt, Aylesbury, Bucks.

AIRCRAFT

(107) **Douglas Skyrocket—highest and fastest.** *Aviation Wk.*, **55**, 14-15 (*16th July*, 1951).
Brief description of rocket-powered version and record flight of 11th June—estimated as Mach 2 at 72,000 ft.

(108) **Firing the AF's first missile in Service use.** *Aviation Wk.*, **55**, 38 (*15th Oct.*, 1951).
Photos of rocket assisted take-off of Matador.

(109) **Rocketcopter.** *Aviation Wk.*, **55**, 17 (*5th Nov.*, 1951).
One-man "knapsack" helicopter driven by two liquid-propellant rocket units. Total weight 100 lb.

ASTRONAUTICS

(110) **The artificial satellite.** E. BURGESS. *Engineer*, **192**, 456-458 (*12th Oct.*, 1951).
Basic requirements for stable orbits including perturbations due to Sun and Earth's bulge. Engineering requirements for an instrument-carrying satellite are considered.

(111) **Space flight talk gets down-to-earth.** J. HUMPHRIES. *Aviation Wk.*, **55**, 21-23 (*22nd Oct.*, 1951).
Review of the papers delivered at Second International Congress on Astronautics.

(112) **Orbital space vehicles for interplanetary flight.** *Aircraft Engng.*, **23**, 334-336 (*Nov.*, 1951).
Abstracts of papers delivered at Second International Congress on Astronautics.

(113) **Toward the conquest of space.** J. HUMPHRIES. *Aircraft*, **30**, 28-29, 58 (*Dec.*, 1951).
Review of papers delivered at Second International Congress on Astronautics.

(114) **Rockets and space-flight.** J. HUMPHRIES. *J. Inc. Plant Engrs.*, **2**, 534-540, 546 (*Sept.-Oct.*, 1951).
Elements of rocket propulsion and its applications.

(115) **A tiltmeter-compass design.** M. CONLEY. *J. Space Flight*, **3**, (8), 1-3 (*Oct.*, 1951).

(116) **The Second International Congress on Astronautics.** A. EULA. *Aerotecnica*, **31**, 300-304 (*Oct.*, 1951). (*In Italian.*)
Information on the Associazione Italiana Razzi, the International Astronautical Federation and a review of the technical papers presented at the Congress.

(117) **The terminology of space flight.** R. HAGEDORN. *J. Space Flight*, **3**, (8), 4-5 (*Oct.*, 1951).

(118) **Landing of spacecraft.** E. G. EWING. *Pacif. Rocket Soc. Bull.*, **4**, (10), B1-B6 (*10th Oct.*, 1951).
Surveys possibilities of using parachutes. Paper presented to Second International Congress on Astronautics.

(119) **How we'll fly to Venus.** *Pop. Sci. Mon.*, **159**, (5), 172-175 (*Nov.*, 1951).

(120) **Power sources for orbital rockets.** L. J. GRANT. *J. Space Flight*, **3**, (9), 1-3 (*Nov.*, 1951).
Considers nuclear and solar sources.

(121) **Considerations on the external ballistics of a man jumping on the surface of the Moon.** D. H. CRONQUIST. *Pacif. Rocket Soc. Bull.*, **4**, (11), B4-B6 (*10th Nov.*, 1951).

(122) **Artificial satellites for the Earth.** J. HUMPHRIES. *Machinery Lloyd*, **23**, 68-73 (*10th Nov.*, 1951). (*In English and Spanish.*)
Review of the technical papers presented at the Second International Congress on Astronautics.

(123) **Dirigibility of rockets.** H. BARTENBACH. *J. Space Flight*, **3**, (10), 1-3 (*Dec.*, 1951).

(124) **An acceleration-deceleration meter design.** M. CONLEY. *J. Space Flight*, **3**, (10), 4-5 (*Dec.*, 1951).

(125) **Space flight technique.** L. HANSEN. *Elektroteknikeren*, (24), 749-757 (*22nd Dec.*, 1951). (*In Danish.*)
Review of rocketry and the basic problems of space-flight.

ATMOSPHERE

(126) **Some phenomena of the upper atmosphere.** S. CHAPMAN. *Proc. Phys. Soc.* (*B*), **64**, 833-844 (*1st Oct.*, 1951).
Reviews recent work on the variation with height of the temperature and mean molecular weight of the air (18 refs.).

BIOLOGY AND MEDICINE

(127) **Physiological aspects of interplanetary travel.** A. V. ST. GERMAIN. *Amer. Helicopter*, **21**, (2), 10-12, 19 (*Jan.*, 1951).
Deals with the supply of oxygen, food and water and the effect of the lack of a gravitational field.

(128) **Physics and psychophysics of weightlessness.** H. HABER and S. J. GERATHEWOHL. *J. Aviation Medicine*, **22**, 180-189 (*June*, 1951).
Examines the psychophysics of the human body under various gravitational conditions, including no-*g*. The vestibular apparatus may cause confusion with regard to orientation under no-*g* but with experience this may be offset by visual impressions.

CHEMISTRY

(129) **Data sheets for chlorine trifluoride.** IMPERIAL CHEMICAL INDUSTRIES, LTD., F1/49, F2/49 and F4/49, 13 pp. (*Sept.*, 1951).
Dealing with handling together with first aid and medical instructions, and design and use of suitable apparatus.

MISCELLANEOUS

(130) **The establishment of an astronautical library.** N. T. SAMET and H. M. SADOWSKI. *J. Space Flight*, **3**, (9), 4-6 (*Nov.*, 1951).

(131) **A punched card system for space flight research.** W. PROELL. *J. Space Flight*, **4**, (1), 1-8 (*Jan.*, 1952).

(132) **The rocket firing submarine.** M. E. HOLBROOK. *U.S. Naval Inst. Proc.*, **77**, 47-51 (*Jan.*, 1951).
Discusses military potentialities.

(133) **French test bed for supersonic speeds.** J. BOYER. *La Nature*, (3190), 60-61 (*Feb.*, 1951). (*In French.*)
Rocket-propelled rail-guided device for measuring forces at trans- and super-sonic speeds.

(134) **Where Services test missiles.** *Aviation Wk.*, **55**, 43-44 (*15th Oct.*, 1951).
Range facilities at the Air Force Missile Test Center, Banana River.

(135) **The Upper Bavarian rocket.** *Inter Avia*, **7**, 27 (*Jan.*, 1952).
Test on dropped container with rocket braking.

PHYSICS

(136) **General method for computation of equilibrium composition and temperature of chemical reactions.** V. N. HUFF and V. E. MORRELL, N.A.C.A. T.N. No. 2113, 47 pp. (*June*, 1950).
A rapidly convergent successive approximation process is described that simultaneously determines both composition and temperature resulting from a chemical reaction. This method is suitable for use with any set of reactants over the complete range of mixture ratios as long as the products of reaction are ideal gases. An approximate treatment of limited amounts of liquids and solids is also included.

(137) **Evidence for ionosphere currents from rocket experiments near the geomagnetic equator.** S. F. SINGER, E. MAPLE and W. A. BOWEN, *J. Geophys. Res.*, **56**, 265-281 (*June*, 1951).
Results from two firings using total-field magnetometers establish existence of a current system in the E region causing the diurnal variation of the earth's magnetic field at sea level. [Brief report in *Phys. Rev.*, **82**, 957-958 (*15th June*, 1951). See *J.B.I.S.*, **11** (*Jan.*, 1952), Abs. No. 35.]

(138) **Measurements of solar extreme ultra-violet and X-rays from rockets by means of a $CaSO_4$: Mn phosphor.** R. TOUSEY, K. WATANABE and J. D. PURCELL. *Phys. Rev.*, **83**, 792-797 (*15th Aug.*, 1951) (18 refs.).

(139) **Astroballistic heat transfer.** R. N. THOMAS and F. L. WHIPPLE. *J. Aero Sci.*, **18**, 636-637 (*Sept.*, 1951).

Some current work on heat transfer to rapidly moving objects is summarized. The work embodies free-flight study of ablation.

(140) **Recent investigation of temperature recovery and heat transmission on cones and cylinders in axial flow in the N.O.L. Aeroballistics Wind Tunnel.** G. R. EBER. *J. Aero. Sci.*, **19**, 1-6, 14 (*Jan.*, 1952).

Tests at Mach numbers from 1·5 to 5·0 (15 refs.).

PROJECTILES

(141) **Comparison between single and multi-stage rockets.** V. RE. *Riv. Maritt. Suppl. Tecn.*, 71-77 (*Dec.*, 1950). (*In Italian.*)

Concludes that a single-stage rocket is more convenient than a multi-stage one.

(142) **An application of Cornu's spiral to the mathematical theory of the motion of an unrotated rocket.** E. T. J. DAVIES and V. MAURANEN. *Math. Gaz.*, **35**, (311), 12-18 (*Feb.*, 1951).

Describes a simple graphical method, based on Cornu's spiral, of obtaining the rocket functions which are needed to give the angular deviations at the end of burning due to constant cross-wind, initial yaw, initial angular velocity, malaligned thrust or malaligned exit-plane centre.

(143) **Evolution of the guided missile.** K. W. GATLAND. *Flight*, Pt. I, **59**, 534-537 (*4th May*, 1951). Pt. II, **59**, 598-600 (*18th May*, 1951). Pt. III, **59**, 768-770 (*29th June*, 1951). Pt. IV, **60**, 45-48 (*13th July*, 1951). Pt. V, **60**, 113-116 (*27th July*, 1951). Pt. VI, **60**, 140-143 (*3rd Aug.*, 1951).

Pt. I. Introduction describing types of control system, command, wire-guidance and beam-rider. Descriptions of ground-to-air missiles including Lark and GAPA. Pt. II. Air-to-air missiles with homing systems and rocket interceptors. Pt. III. Long range ground to ground missiles with special reference to A.4, A.4*b*, A.9/A.10 and Rheinbote. Pt. IV. Sounding rockets for high altitude research. Descriptions of WAC Corporal, Aerobee, Viking and modified A.4's. Pt. V. Earth-satellite vehicles with details of instrument-carrying close-orbit vehicle. Pt. VI. Interplanetary flight, atomic powered rockets and orbital techniques.

(144) **Probing the atmosphere with rockets.** G. R. HILL. *J. Amer. Soc. Naval Engrs.*, **63**, 293-310 (*May*, 1951).

Deals mainly with the Viking research missile and its applications. Details of the first five flights are given and some of the experimental results are discussed.

(145) **Swiss show anti-aircraft guided missile system.** *Aviation Wk.*, **55**, 18 (*17th Sept.*, 1951).

Oerlikon missile, launcher and control system.

(146) **All technology not mastered.** D. A. ANDERTON. *Aviation Wk.*, **55**, 125-126, 129-130, 133 (*24th Sept.*, 1951).

Deals with the problems of large-scale missile production.

(147) **A comparison of rocket propulsion at constant thrust and at constant acceleration.** K. A. EHRICKE. *Rocketscience*, **5**, 50-63 (*Sept.*, 1951).

General equations are derived for a quantitative comparison and a trajectory factor is introduced which shows the ratio of summit altitudes in both cases as a function of rocket loading factor and acceleration.

(148) **A new altitude record for a single-step rocket.** *Umschau*, **51**, 656-657 (*1st Nov.*, 1951).

Viking No. 7, 7th Aug., 1951. (*In German.*)

ROCKET MOTORS

(149) **An analysis of a compound pendulum rocket suspension.** J. C. NORRIS. Galcit Thesis No. 273, 66 pp. (1951).

Discussion of principles, equations of motion, numerical calculation of stability and discussion of results.

(150) **Designing a JATO unit.** W. L. ROGERS. *Machine Design*, **23**, 102-106 (*Jan.*, 1951).

Design features of the Aerojet solid propellant 14AS-1000 unit. Deals in detail with propellant charge and chamber, nozzle and igniter assemblies. Also discusses earlier experimental nozzle and igniter designs with reasons for their abandonment.

(151) **Measurement of velocity and pressure of gases in rocket flames by spectroscopic methods.** F. P. BUNDY, H. M. STRONG and A. B. GREGG. *J. Appl. Phys.*, **22**, 1069-1077 (*Aug.*, 1951).

This method is based on the Doppler shift of wavelength of the sodium or lithium spectral radiation from the flame when viewed at different angles relative to the flame axis. The same apparatus may be used to measure the gas pressure from the pressure shift of wavelength of the sodium radiation. The absolute accuracy of any one velocity measurement by this method is about $\pm 1{\cdot}5 \times 10^4$ cm./sec., while that of any one pressure measurement is about $\pm 0{\cdot}3$ atmos.

(152) **Nuclear-energy propulsion.** L. N. THOMPSON. *Flight*, **60**, 656-658 (*23rd Nov.*, 1951).

Use of pure nuclear fuel is not feasible; use of working fluid feasible but offers no competition to chemical rockets.

(153) **Liquid propellant rockets and their applications.** J. HUMPHRIES. *Machinery Lloyd*, **23**, 68-79 (*24th Nov.*, 1951). (*In English and Spanish.*)

Review of the elements of rockets and their applications to aircraft and projectiles.

(154) **Time dependence of pressure in restricted burning solid propellant rocket motors.** M. G. WHYBRA. *Rocketscience*, **5**, 74-82 (*Dec.*, 1951).

Derives and solves basic differential equations.

(155) **Heat transfer in rocket motors and the application of film and sweat cooling.** R. H. BODEN. *Trans. Amer. Soc. Mech. Engrs.*, **73**, 385-390 (*May*, 1951).

Discusses the distribution of heat transfer in rocket motors, a number of factors which influence it, and finally, the experimental investigation of film cooling.

(156) **Fuel feeding mechanism for detonating combustion apparatus.** R. H. GODDARD. *U.S. Pat. No.* 2,563,022 (*7th Aug.*, 1951).

(157) **Combustion chamber with multiple discharge nozzles.** R. H. GODDARD. *U.S. Pat. No.* 2,563,023 (*7th Aug.*, 1951).

(158) **Auxiliary turbine and pump for combustion chambers.** R. H. GODDARD. *U.S. Pat. No.* 2,563,025 (*7th Aug.*, 1951).

(159) **Opposed conical jacket wall rotary combustion chamber.** R. H. GODDARD. *U.S. Pat. No.* 2,563,026 (*7th Aug.*, 1951).

(160) **Device for opening up streams of combustion gases.** R. H. GODDARD. *U.S. Pat. No.* 2,563,027 (*7th Aug.*, 1951).

(161) **Combustion apparatus comprising a combustion chamber with target type premixing extension.** R. H. GODDARD. *U.S. Pat. No.* 2,563,028 (*7th Aug.*, 1951).

(162) **Jacketed reaction nozzle with hollow spiral vanes for rocket motors.** R. H. GODDARD. *U.S. Pat. No.* 2,563,029 (*7th Aug.*, 1951).

(163) **Details of British Snarler revealed.** *Aviation Wk.*, **55**, 36 (*29th Oct.*, 1951).

ROCKET PROPELLANTS

(164) **The petrochemical engineer looks at rocket fuels.** M. SITTIG. *Petroleum Refiner*, **30**, 115-116 (1951).

Discussion of present and proposed propellants and their manufacture.

(165) **An apparatus for measuring the rates of some rapid reactions.** C. D. MCKINNEY and M. KILPATRICK. *Rev. Sci. Instrum.*, **22**, 590-597 (*Aug.*, 1951).

As a means of studying the kinetics of rapid reactions in which a gas is evolved, a constant volume reactor has been designed. This reactor employs a static technique in which the reaction is followed by the increase in pressure as the gas is evolved. The apparatus is capable of contacting 1 ml. of one reactant with 25 ml. of a second reactant and obtaining effective mixing in less than 10 milliseconds.

(166) **Spontaneous ignition of gasoline and nitric acid.** G. B. KISTIAKOWSKY. *U.S. Pat. No.* 2,563,532 (*7th Aug.*, 1951).

REVIEWS

Radio Astronomy

(By B. Lovell and J. A. Clegg. 238 pp., 119 figs. Chapman & Hall, 1952. Price 16s.)

This is the first book in one of the most important, and certainly most exciting, branches of modern science. Radio astronomy is not yet ten years old, but already it has made some spectacular discoveries and has suggested that our picture of the universe is about to suffer drastic changes.

The first four chapters of the book, as is inevitable in a work dealing with two sciences which until recently were quite unrelated, deals with fundamentals. The basic ideas of celestial co-ordinates, mean and sidereal time, orbits, and the Galaxy are explained for the benefit of the radio engineers, while in the next two chapters electromagnetic wave propagation, polar diagrams, power gain, aerial arrays, pulse techniques, displays, bandwidth and noise are explained for the benefit of the astronomers.

The next third of the book deals with meteors and the ingenious radar techniques now used to determine their radiants and velocities. Only a few years ago the origin of sporadic meteors was one of the most controversial questions in astronomy, one school of workers holding that the majority were not denizens of the Solar System, but visitors from interstellar space. The new radio methods have now conclusively shown that this is not the case. Undoubtedly the most impressive achievement of the radio techniques, however, has been the detection of the tremendous daylight showers which could never have been discovered by any other means.

The next five chapters deal with radio waves from the Sun—a subject with which one of our Fellows, Dr. D. F. Martyn, is closely associated. Here the authors have an exceedingly difficult task, as there is no general agreement concerning the mechanism by which this radiation is produced.

The same is true, even more acutely, of the radio waves which have now been detected from the Galaxy and the Andromeda nebula. The recently discovered "radio stars," which are quite invisible optically, have presented astronomy with one of its most baffling problems and has even suggested that there may be twice as many stars in the Galaxy as we had hitherto imagined.

Of particular interest to our members will be the last two chapters, which discuss radio investigations of the Moon and the possibility of extending these techniques to the planets. The authors calculate that with a 250-foot aperture paraboloid as aerial, a wavelength of 1·5 m. and a peak power of 200 kW., it would be possible to obtain echoes from Mars, Venus, Mercury and Jupiter, as well as such bodies as Hermes and Eros at their closest approaches. "It is of interest to note," they remark, "that a body the size of an average aircraft could be detected at distances further away than the Moon."

This book, which is well produced and pleasant to handle, is an undoubted "must" for anyone interested in the new astronomical frontiers. Though the price is somewhat high, it cannot in these days, unfortunately, be regarded as excessive—particularly for a book which is likely to remain unique for a considerable time.

A. C. C.

The Diameters of Lunar Craters. Part I

(By D. W. G. Arthur, F.R.A.S. Published by the Author, 35, Vastern Road, Reading, Berks., 1951. Price 3s.)

This catalogue of the diameters of lunar craters has been compiled from a study of the best available photographs, and will be completed in three further issues.

The lack of a really reliable diameter catalogue has long been felt, and this work fills a serious gap in the literature. It will, in fact, become invaluable to the observational selenographer, as it is much more reliable than any list of measures previously published. The reproduction is clear, and there are no important misprints. P. A. M.

Viajes Interplanetarios
(Interplanetary Travel)

(By J. A. Kindelam. 78 pp. Pub. by Editorial Saso, Av. de José Antonio, Madrid, 1951.)

This is a small popular book on astronautics for the layman. It opens by discussing the possibility of life on other planets, and the author decides (optimistically!) that human beings would probably feel at home on Venus.

In the section dealing with propulsion, he considers constant acceleration for the entire journey to obtain artificial gravity, and assumes that the direct utilization of nuclear energy will become available. Such problems as temperature control, the composition of the crew, guidance, orientation and landing are also dealt with.

Though the book contains some errors, it should succeed in its aim of introducing space-flight to the public. T. M. V.

Rockets, Jets, Guided Missiles and Space Ships

(By Jack Coggins and Fletcher Pratt. 60 pp. Pub. by Random House (New York). With an introduction by Willy Ley. Price 7s. 6d. net.)

Although there is no mention of the fact, the writing is presumably by the Fletcher Pratt who, with David Lasser, C. P. Mason, G. Edward Pendray, and others, founded the American Interplanetary Society (now the A.R.S.) in 1930. At all events, here is to be found a concise and well informed account of rocket development through the ages, with the accent on recent achievement, and on future possibilities. As a brief introduction, addressed to the uninitiated, particularly of the younger generation, the account could hardly be bettered.

The writing, however, runs to a mere 12,000 words or so, and the main feature of the book is provided by artist Jack Coggins. His contribution occupies some two-thirds of the available space, and the 70-odd illustrations, at least one to every page, and many of them multi-coloured, are superbly done. The work, in short, follows the well known Bonestell-Ley pattern, with excellent results.

It is a sad commentary on the times that no less than 30 of the book's 60 pages are necessarily concerned with the rocket as a weapon of war—evidence enough of the baneful influence of *Homo bellicosus*. P. E. C.

Men of Other Planets

(By K. Heuer. x + 160 pp., with illustrations by R. T. Crane. Victor Gollancz Ltd., London, 1951. Price 12s. 6d. net.)

One should not be mislead by the title of this book for, shorn of its fancy trimmings, it remains little more than a popular account of the planets of the solar system, and a discussion of the possibility of other planetary systems. The account, however, is written without any appreciation of the problems of research in these subjects, and the information given seems to have been gleaned from a rather uncritical perusal of one of the plethora of popular astronomical books; the reader who wishes to learn of planetary astronomy should consult a reliable astronomical book, and not the present volume. One example to show how uncritical is this discussion of planetary physics may be given. After correctly learning that on the Moon, owing to the virtual absence of atmosphere, there can be no sound, we read that for this reason "the *blizzards* do not howl." Established fact and doubtful suggestion, even in the strictly astronomical passages, jostle together in a manner determined, apparently, only by the author's prejudice.

For Mr. Heuer has a large-sized bee in his bonnet, and the result on paper is not, unfortunately, an annoying but tolerable buzzing, rather a cacophony. The author's general argument runs thus: life is found under all physical conditions on the Earth, and therefore, *ipso facto*, it can and does exist under all physical conditions throughout the universe. Although astrophysics is in scientific discipline the least conducive to athropomorphism, Mr. Heuer constantly tilts at astronomers for not accepting this conclusion.

Let us examine the problem impartially. It is true that life seems able to adapt itself to the extremes of environment found on the Earth, but this is no guarantee that its adaptability spreads to the vastly greater ranges of conditions found in the universe. Even if it does, however, immediately to draw the conclusion that where life could exist, it does, is to ignore the indications of biology. For it would seem at least possible that all life on the Earth developed from a single stock, and that the conditions for the development of the first primitive "life molecules" must have been rather stringent (see Prof. Bernal's address to the Physical Society on the "Physical Basis of Life, *Proc. Phys. Soc., Sect. B*, 1949, **62**, 597), and therefore only of very rare occurrence in the universe. With these possibilities, and with the present ignorance of the origin of life on the Earth, the assertion of the existence of life on other planets is without foundation. The most that can reasonably be discussed scientifically is a comparison of conditions on the other planets with those on the Earth, and how life as we know it on the Earth (doubtless the product of many chance conditions throughout evolutionary history) would fare under such conditions. But perhaps a more cogent reason for refraining from discussion of extra-terrestrial life is that it has not yet proved possible to give any definition of "life" at all. Perhaps even the distinction between the animate and the inanimate is a purely human conception.

However, all this said, Mr. Heuer is able to maintain as a speculative possibility that life could exist on other planets. Accepting this, he has the

opportunity of discussing the conditions of the planets in terms of the possible life-forms that might have developed there in the light of the various ways in which terrestrial life has adapted itself to extremes. Unfortunately, no such attempt is made. The references to life on other worlds, frequent as they are, are quite uninformative in this way. Instead, we read such imaginative passages as: ". . . the inhabitants of the (lunar) forest . . . appear to be digging holes, evidently planting a garden. But they set nothing in the holes; and having covered them with sticks and ashes, they go a little distance off and hide behind the (lunar) bushes . . . eyes gleam from behind the bushes, and we hear the men laugh in the dark." Or again, that because of the extremes of temperature on Mercury, except in the libration (incorrectly termed "twilight") zone, ". . . everyone who is anyone (on Mercury) lives in the twilight zone, this region being the most desirable. We can imagine a Mercurian housewife on the sunward side of the planet telling another, 'Oh, there is such dreadfully hot weather in this section. We're moving to the twilight zone as soon as George gets his rise!'" Even if included for humour, these remarks are surely anthropomorphism with a vengeance!

In the main, then, this book represents a wasted opportunity, the more unfortunate in that the author has a certain facility in tossing off "cold facts" with an attractive air. If Mr. Heuer had only come to terms with his obsession with extra-terrestrial life, and made an attempt to discuss the problem calmly and logically, we might have found his book interesting and have looked forward to his promised sequel volume on "the theories of the end of the world" with pleasure instead of, as now, with unleavened gloom.

Finally, it is recorded, in wonder, that a preface is given by the Chairman of the Astronomy Department of Brown University. Really, Dr. Smiley!

M. W. O.

Hockfrequenztechnik und Weltraumfahrt
(High Frequency Technique and Space-flight)

(Edited by Dr. R. Merton, G.f.W., published by S. Hirzel, Stuttgart, Germany, 1951, 116 pp. DM. 7.)

This booklet contains eight papers delivered at the Fourth Annual Meeting of the G.f.W.

The first paper is "Spaceflight and the Ionosphere," by Dieminger and deals with the frequency band usable for communication and navigation, and several problems which the high altitude rocket may aid to solve, e.g. a detailed picture of the ionospheric layers and investigation into the Earth's magnetic field. This is followed by "Present State of the cm-wave Technique," by Doering, and "Ranges by Radar," by Stepp.

Of particular interest to members are "Fundamentals on Antennas for Spaceships," by Gundlach, and "Communications with the Earth-satellite-vehicle," by Merton, the latter showing the different systems of radiocommunication and the conditions for the cheapest and safest communication between space-station and ground-station.

Other interesting papers are "Navigation with cm. Waves," by Ulbricht,

"Control and Stability of Spaceships," by Kirschstein (which reports on the V.2 guidance and control systems and describes the Nyquist criterion for stability), and "Measuring Velocity by Doppler principles," by Mosch, which describes the equipment developed by Professor Wolman for the V.2.

All the subjects appear to have been well dealt with, and it is the intention of the GfW to establish several working groups to deal with certain major problems. In general, a close relation is kept with present day knowledge (notably concerning the V.2), for experience drawn from such sources will undoubedtedly enrich research into the much wider field of interplanetary flight later on.

The book is highly recommended to readers interested in the application of HF technique to interplanetary flight. DR. O. H. LANGE.

Guided Missiles: Rockets and Torpedoes

(By Frank Ross, Jr. 186 pp. Lothrop, Lee and Shepard Co., Inc., New York. Price $2·75.)

This book surveys in general terms the whole field of missile development to recent date and will appeal particularly to the younger reader. There is a short introduction on rocket history, and wartime and post-war developments in Germany and America respectively are the subjects of separate chapters. The emphasis throughout is on the military aspect, although a small section is devoted to high-altitude research. Only in the final chapter, "The Future and Guided Missiles," is space flight discussed.

The author has clearly gone to some trouble to obtain the latest available data and, on the whole, the information he supplies is reliable, if somewhat inadequate in detail. There are, however, one or two obvious errors: in the German section, the payload of the Rhinebote step-rocket is given as 1,100 lb. instead of 88·8 lb. The chapter dealing with the German "A" series is too brief to deal adequately with this important aspect of the history and A.5 is wrongly stated to have emerged after the A.4 (V.2), whereas it was actually the small-scale prototype of the latter originating in 1938.

In "The Future and Guided Missiles," emphasis is given (rightly!) to the Earth satellite vehicle, although one is surprised to find that: "These . . . will have speeds of at least 25,200 miles per hour, in order to fly beyond the Earth's gravitational pull. . . ." The satellite vehicle is held to be a powerful weapon, i.e., "The nation first able to send one of these aloft would be in a position to conquer the world." To this reviewer, both this and the suggestion that "No area on this Earth would be safe from attack by bombardment with missile weapons which could be launched from such a space station," should be treated with reserve, for second thoughts will show that the techniques already adopted for launching long-range missiles are likely to remain valid, for two principal reasons: (*a*) mass ratio considerations, which strongly favour the case of a missile launched directly from the surface, and (*b*) the extreme vulnerability of such a satellite, the position of which could be determined with mathematical precision for destruction by counter-launched missiles.

Finally, in fairness to the originator of an idea, one would have expected to see the name of Arthur C. Clarke* associated with the proposed use of satellite relay stations for television, instead of H. P. Haviland of the General Electric Co.

The author is to be complimented on presenting so excellent a collection of photographs (there are more than 100), particularly those showing the launching of the German missiles Rhinetochter, Wasserfall, Schmetterling and Enzian.

K. W. G.

Rockets and Jets

(By Marie Neurath, 36 pages, pub. by Max Parrish, London, W.1, in colour, 6s. net.)

This attractively illustrated picture book for children explains how rockets and jet planes work in simple terms such as should readily be understood by quite young children. If one or two of the statements made about rockets suffer in accuracy through over-simplification, and if the spaceship of page 34 looks over-prosperous to the technically critical eye, still one must commend the educative intent and admire the excellent presentation. Aimed one age-group higher it might have been a winner. How it will compete with fairies and dragons remains to be seen.

H. E. R.

* See "Extraterrestrial Relays," *Wireless World*, October, 1945.

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The aim should be to make the summary intelligible in itself, without reference to the main paper.

References

References should be indicated in the text by the use of small consecutive numerals, and appear as a numbered list at the end of the paper.

When setting these out in the appendix, the following standard form should be adhered to—

REFERENCES

(1) A. D. Baxter, "Combustion in the Rocket Motor," *J.B.I.S.*, **10** (3), 123–138, May, 1951.

(2) G. P. Kuiper (ed.), *The Atmospheres of the Earth and Planets*, Univ. of Chicago Press, 1949, p. 246.

The titles of publications in the MSS. should be underlined whether for a periodical or book. This indicates that the titles will be set up in italic print, as above.

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